Land Cover Classification System (LCCS): Classification Concepts and User Manual

For software version 1.0

by

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Food and Agriculture Organization of the United Nations, Rome, 1998

The conclusions given in this report are considered appropriate at the time of its preparation. They may be modified in the light of further knowledge gained at subsequent stages of the project.

Land Cover Classification System (LCCS): Classification Concepts and User Manual.
Di Gregorio, A., and Jansen, L.J.M. Environment and Natural Resources Service, GCP/RAF/287/ITA Africover - East Africa Project and Soil Resources, Management and Conservation Service. 157pages, 28 figures and 3 tables.
FAO, Rome. 1998.

SUMMARY

The Land Cover Classification System (LCCS) is a comprehensive, standardized *a priori* classification system, designed to meet specific user requirements, and created for mapping exercises, independent of the scale or means used to map. Any land cover identified anywhere in the world can be readily accommodated. The classification uses a set of independent diagnostic criteria that allow correlation with existing classifications and legends.

Land cover classes are defined by a combination of a set of independent diagnostic criteria – the so-called classifiers – which are hierarchically arranged to assure a high degree of geographical accuracy. Because of the heterogeneity of land cover, the same set of classifiers cannot be used to define all land cover types. The hierarchical structure of the classifiers may differ from one land cover type to another. Therefore, the classification has two main phases:

- an initial *Dichotomous Phase*, where eight major land cover types are distinguished; and

- a subsequent *Modular-Hierarchical Phase* where the set of classifiers and their hierarchical arrangement are tailored to the major land cover type.

This approach allows the use of the most appropriate classifiers and reduces the total number of impractical combinations of classifiers. Because of the complexity of the classification and the need for standardization, a software program has been developed to assist the interpretation process. This will reduce heterogeneity between interpreters and between interpretations over time. Because of the flexible manner in which the classification is set up, with creation of classes at different levels of the system and the optional use of modifiers, environmental attributes and specific technical attributes in combination, coupled with the tremendous number of classes possible, this innovative software program assists the user to select the appropriate class using a step-by-step process, i.e., classifier by classifier. The software program will be available both as a stand-alone product and integrated into a digital image interpretation software suite which will allow interpretation of imagery followed by labelling of the mapping units with the land cover classes.

The classification system leads to mutually exclusive land cover classes, which comprise: (1) a unique Boolean formula (a coded string of classifiers used); (2) a standard name; and (3) a unique numerical code. Both the numerical code and standard name can be used to build an automatically generated Legend, with the classes created grouped according to the main land cover categories and their domains according to the level of detail. The nomenclature can be linked to a user-defined name in any language.

Further definition of the Land Cover Class can be achieved by adding attributes. Two types of attributes, which form separate levels in the classification, are distinguished:

- *Environmental Attributes*: these are attributes (e.g., climate, landform, altitude, soil, lithology and erosion) which influence land cover but are not inherent features of it and should not be mixed with "pure" land cover classifiers; and

- *Specific Technical Attributes*: these are associated with specific technical disciplines (e.g., for (Semi-)Natural Vegetation, the Floristic Aspect can be added; for Cultivated Areas, the Crop Type; and for Bare Soil, the Soil Type).

All *Primarily Vegetated* land cover classes are derived from a consistent physiognomic-structural conceptual approach that combines the classifiers *Life Form, Cover* and *Height* (in (Semi)Natural Vegetation) and *Life Form* (in Cultivated Areas) with *Spatial Distribution*. The *Primarily Non-Vegetated* classes have a similar approach, using classifiers which deal with surface aspects, distribution/density and height/depth.

The advantages of the classifier, or parametric, approach are manifold. The system created is a highly flexible *a priori* land cover classification in which each land cover class is clearly and systematically defined, thus providing internal consistency. The system is truly hierarchical and applicable at a variety of scales. Re-arrangement of the classes based on re-grouping of the classifiers used facilitates extensive use of the outputs by a wide variety of end-users. Accuracy assessment of the end product can be generated by class or by the individual classifiers forming the class. All land covers can be accommodated in this highly flexible system; the classification could therefore serve as a universally applicable reference base for land cover, thus contributing towards data harmonization and standardization.

Keywords:
land cover, classification, classification system, standardization, harmonization.

ACKNOWLEDGEMENTS

The Land Cover Classification System (LCCS) is the result of an initiative to take a first step towards an internationally agreed reference base for land cover. The objectives of the Africover Programme of the Environment and Natural Resources Service (SDRN), FAO, are to develop an approach for concepualizing, defining and classifying land cover that coincides with the UNEP/FAO initiative on harmonization of land cover and land use classifications. The first full operational version of the classification and software program has been developed for implementation by the first project to use this classification system, the Government of Italy Trust Fund project GCP/RAF/287/ITA *Africover - East Africa Project* in collaboration with the Environment and Natural Resources Service (SDRN) and the Soil Resources, Management and Conservation Service (AGLS) of FAO.

These land cover classification concepts were discussed and endorsed at the meeting of the international *Working Group on Classification and Legend* (Senegal, July 1996) supported by Government of France Trust Fund GCP/RAF/311/FRA (FAO, 1997).

The following are thanked for their substantial contribution to the software application: Luca Morandini , Antonio Martucci, and Wolfgang Prante, for the software programming; Keya Choudhury, for preparing the Glossary; and Thorgeir Lawrence, for the technical editing of the text. In general, the support of John Latham, Dominique Lantieri, Denis Sims and Freddy Nachtergaele is appreciated.

For valuable feedback and review of the classification system, discussions with a wide range of experts from all over the world were appreciated. Those who attended the Africover Workshop on Classification and Legend, Sally Portudal, Senegal, July 1996, are thanked, as well as those who responded to earlier versions of the system, especially the U.S. Federal Geographic Data Committee - Vegetation Subcommittee and Earth Cover Working Group, Washington, October 1996 and Rome, January 1997 (with special thanks to Gyde Lund of the USDA Forest Service, Washington, D.C.); the LANES concerted action funded under the 4th Framework Programme of Research on Environment and Climate of the European Commission, which focused on the development of a harmonized framework for multipurpose land cover and land use information (with special thanks to Christophe Duhamel of CESD-Communautaire, Luxembourg, co-ordinating the LANES concerted action). Furthermore, Prof. Dr. Salomon B. Kroonenberg of the Geology Section, Subfaculty of Applied Earth Sciences, Delft University of Technology, The Netherlands, is thanked for provision of the information on lithology. Finally, UNEP is gratefully acknowledged for the financial contribution to this publication.

Antonio Di Gregorio and Louisa J.M. Jansen, August 1998

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– PART A –

Land Cover Classification System:
A Dichotomous,
Modular-Hierarchical Approach

Classification Concepts

INTRODUCTION

Classification is easy:
it is something you just do.
F.C. Bawden

A fool sees not the same tree
that a wise man sees.
W. Blake, *Marriage of Heaven and Hell*

The main resource controlling primary productivity for terrestrial ecosystems can be defined in terms of land: the area of land available, land quality and the soil moisture characteristics. Despite successful substitution of land-based resources with fossil fuels and mineral resources, land remains of prime importance (Darwin *et al*., 1996). Land cover and land use represent the integrating elements of the resource base. Changes in land cover and land use affect the global systems (e.g., atmosphere, climate and sea level) or they occur in a localized fashion in enough places to add up to a significant total (Meyer and Turner, 1992). Land cover is the expression of human activities and as such changes with alterations in these. Hence, land cover is a geographical feature which may form a reference base for applications ranging from forest and rangeland monitoring, production of statistics, planning, investment, biodiversity, climate change, to desertification control.

People have reshaped the earth continually but the present magnitude and rate are unprecedented. Nowadays it is realized that it is very important to know how land cover has changed over time, in order to make assessments of the changes one could expect in the (near) future and the impact these changes will have on peoples' lives. As people are the main users of the land, it is important for any system to be oriented towards them.

Due to the lack of appropriate land cover data, many assessments have used models to delimit potential land cover (e.g., Alexandratos, 1995). Although the use of potential land cover is important in modelling simulated future scenarios, there are major limitations. Information describing current land cover is an important input for planning and modelling, but the quality of such data defines the reliability of the simulation outputs (Townshend, 1992; Belward, 1996).

In addition to a high demand for improved land cover data sets because of an increasing need to be able to precisely describe and classify land cover in order to develop sustainable land use systems, there is also a growing need for standardization and compatibility between data sets and for the possibility to map, evaluate and monitor wide areas (Di Gregorio, 1991, Reichert and Di Gregorio, 1995; Thompson, 1996; FAO, 1995 and 1997). Technical advances, such as the vast amount of remote sensing data that has become available from earth observation satellites, makes this increasingly possible (Di Gregorio, 1995).

In 1993, UNEP and FAO organized a meeting to catalyse co-ordinated action towards harmonization of data collection and management and to take a first step towards an internationally agreed reference base for land cover and land use (UNEP/FAO, 1994). The Africover Programme of the Environment and Natural Resources Service (SDRN), which intends to map land cover for the whole of Africa, needed a land cover reference system for operational use.

The objectives of the Africover Programme are to:

- respond to the need for land cover data of a variety of end-users;
- apply the methodology in mapping exercises, independent of the means used, which may range from high resolution satellite imagery to aerial photography;
- link with existing classifications and legends, allowing comparison and correlation; and
- support, to the extent possible, international ongoing initiatives on classification and definition of land cover.

The main objective of the initiative for definition of a reference classification is to respond to the need for standardization (or harmonized collection of data, as mentioned in UNCED's Agenda 21 Chapter 10, for which FAO is Task Manager within the UN system) and to develop a common integrated approach to all aspects of land cover. This implies a methodology that is applicable at any scale, and which is comprehensive in the sense that any land cover identified anywhere in the world can be readily accommodated.

Existing published classifications and legends, as well as nomenclatures, were analysed (Danserau, 1961; Fosberg, 1961; Eiten, 1968; UNESCO, 1973; Mueller-Dombois and Ellenberg, 1974; Anderson *et al*., 1976; Kuechler and Zonneveld, 1988; CEC, 1993; UNEP/FAO, 1994; Duhamel, 1995; Beek, De Bie and Driessen, 1997), together with relevant FAO documents (Nègre, 1995; Barisano, 1996; Wyatt *et al*., unpubl.).

The initial concepts of the classification were discussed by the international Africover Working Group on Classification and Legend (Senegal, July 1996) (Di Gregorio and Jansen, 1996c; FAO, 1997). While fully developing the system, links with other international ongoing activities on classification of land cover were developed, such as the U.S. Federal Geographic Data Committee (FGDC) - Vegetation Subcommittee and Earth Cover Working Group (ECWG); the South African National Land Cover Database Project (Thompson, 1996); and the International Geosphere-Biosphere Programme (IGBP) - Data and Information System (DIS) Land Cover Working Group and Land Use and Land Cover Change (LUCC) Core Project. The first full operational version of the classification and software program has been developed by project GCP/RAF/287/ITA *Africover - East Africa* in co-operation with the Soil Resources, Management and Conservation Service (AGLS), FAO.

The approach developed for land cover could serve as the basis for a reference classification system with links to specific expertise, because it describes and allows correlation of land cover with a set of independent diagnostic criteria, the so-called classifiers, rather than being nomenclature based. Also, existing classifications and legends can be "translated" into the reference system, thus facilitating the use of existing historical materials. Re-arrangement of the classes, based on re-grouping of the used classifiers, facilitates the extensive use of the outputs by a wide variety of end-users.

1. DEFINITIONS

1.1 LAND COVER

The definition of land cover is fundamental, because in many existing classifications and legends it is confused with land use. It is defined as:

Land cover is the observed (bio)physical cover on the earth's surface.

When considering land cover in a very pure and strict sense it should be confined to describe vegetation and man-made features. Consequently, areas where the surface consists of bare rock or bare soil are describing *land* itself rather than land *cover*. Also, it is disputable whether water surfaces are real land cover. However, in practise, the scientific community usually describes those aspects under the term land cover.

Land use is characterized by *the arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it*. Definition of land use in this way establishes a direct link between land cover and the actions of people in their environment.

The following examples are a further illustration of the above definitions:

- "grassland" is a cover term, while "rangeland" or "tennis court" refer to the use of a grass cover; and
- "recreation area" is a land use term that may be applicable to different land cover types: for instance sandy surfaces like a beach; a built-up area like a pleasure park; or woodlands; etc.

1.2 CLASSIFICATION AND LEGEND

Classification is an abstract representation of the situation in the field using well-defined diagnostic criteria: the classifiers (Figures 1 and 2). Sokal (1974) defined it as: "the ordering or arrangement of objects into groups or sets on the basis of their relationships." A classification describes the systematic framework with the names of the classes and the criteria used to distinguish them, and the relation between classes. Classification thus necessarily involves definition of class boundaries that should be clear, precise, possibly quantitative, and based upon objective criteria.

A classification should therefore be:

- *Scale independent,* meaning that the classes at all levels of the system should be applicable at any scale or level of detail; and
- *Source independent,* implying that it is independent of the means used to collect information, whether satellite imagery, aerial photography, field survey or some combination of them is used.

A *legend* is the application of a classification in a specific area using a defined mapping scale and specific data set (Figure 3). Therefore a legend may contain only a proportion, or sub-set, of all possible classes of the classification. Thus, a legend is:

- *Scale and cartographic representation dependent* (e.g., occurrence of mixed mapping units if the elements composing this unit are too small to be delineated independently); and

- *Data and mapping methodology dependent* (e.g., an aerial photograph shows different features compared to a satellite false colour composite image).

FIGURE 1.
Abstract presentation of a classification consisting of a continuum with two gradients: circles and triangles in red and white representing the actual situation in Figure 2. (From Kuechler and Zonneveld, 1988).

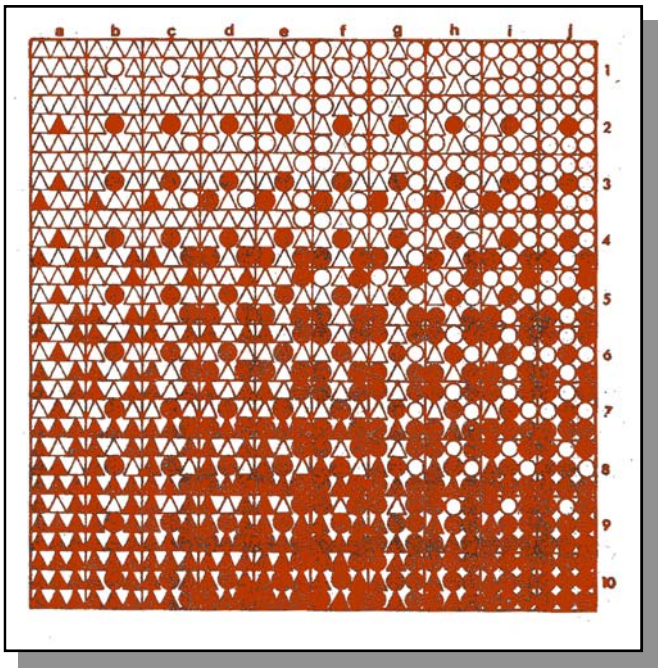


FIGURE 2. **Concrete situation in the filed in a particular area (From Kuechler and Zonneveld, 1988).**

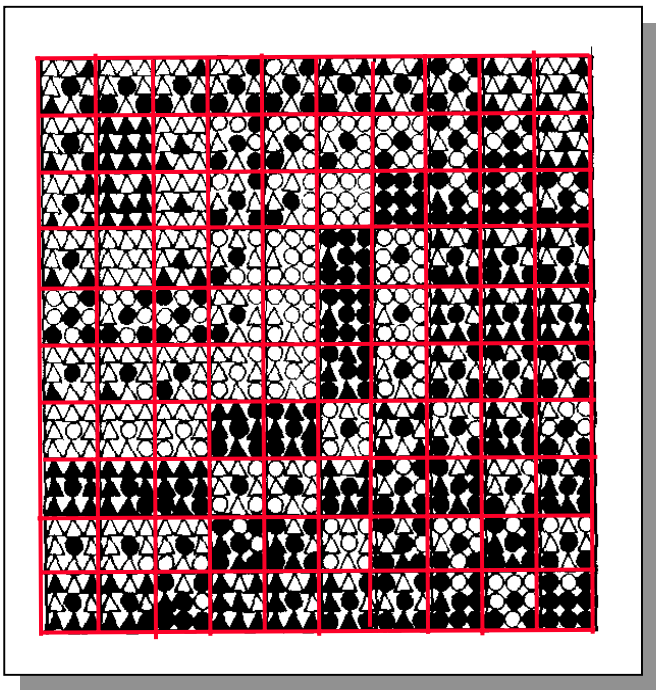
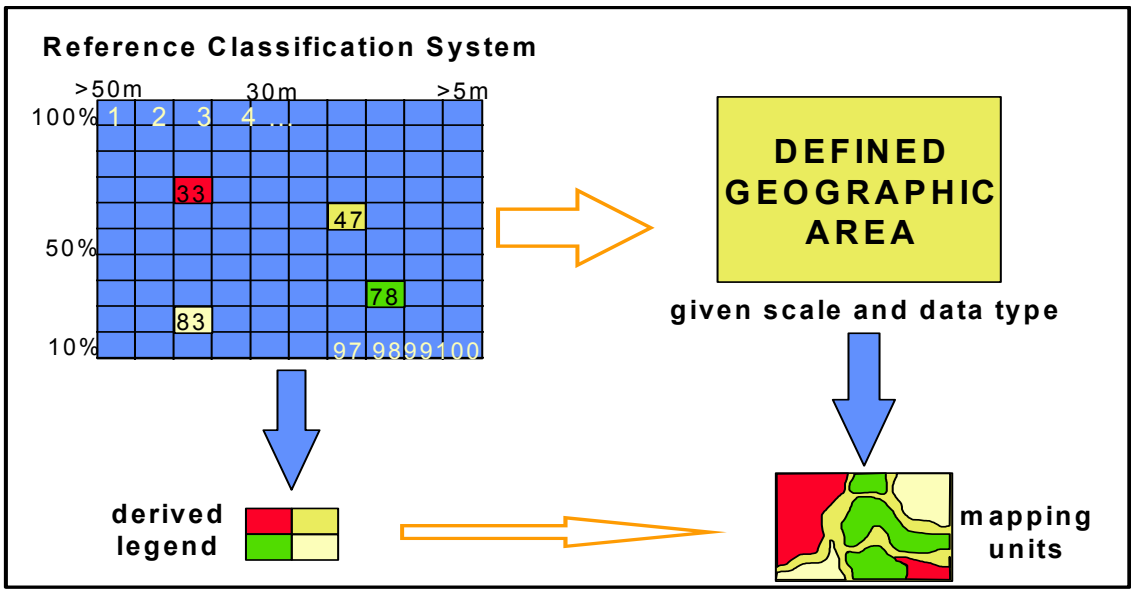


FIGURE 3.
Legend as application of a classification in a particular area.



1.3 HIERARCHICAL VERSUS NON-HIERARCHICAL SYSTEMS

Classification systems come in two basic formats, *hierarchical* and *non-hierarchical*. Most systems are hierarchically structured because such a classification offers more consistency owing to its ability to accommodate different levels of information, starting with structured broad-level classes, which allow further systematic subdivision into more detailed sub-classes. At each level the defined classes are mutually exclusive. At the higher levels of the classification system few diagnostic criteria are used, whereas at the lower levels the number of diagnostic criteria increases. Criteria used at one level of the classification should not be repeated at another, i.e., lower, level.

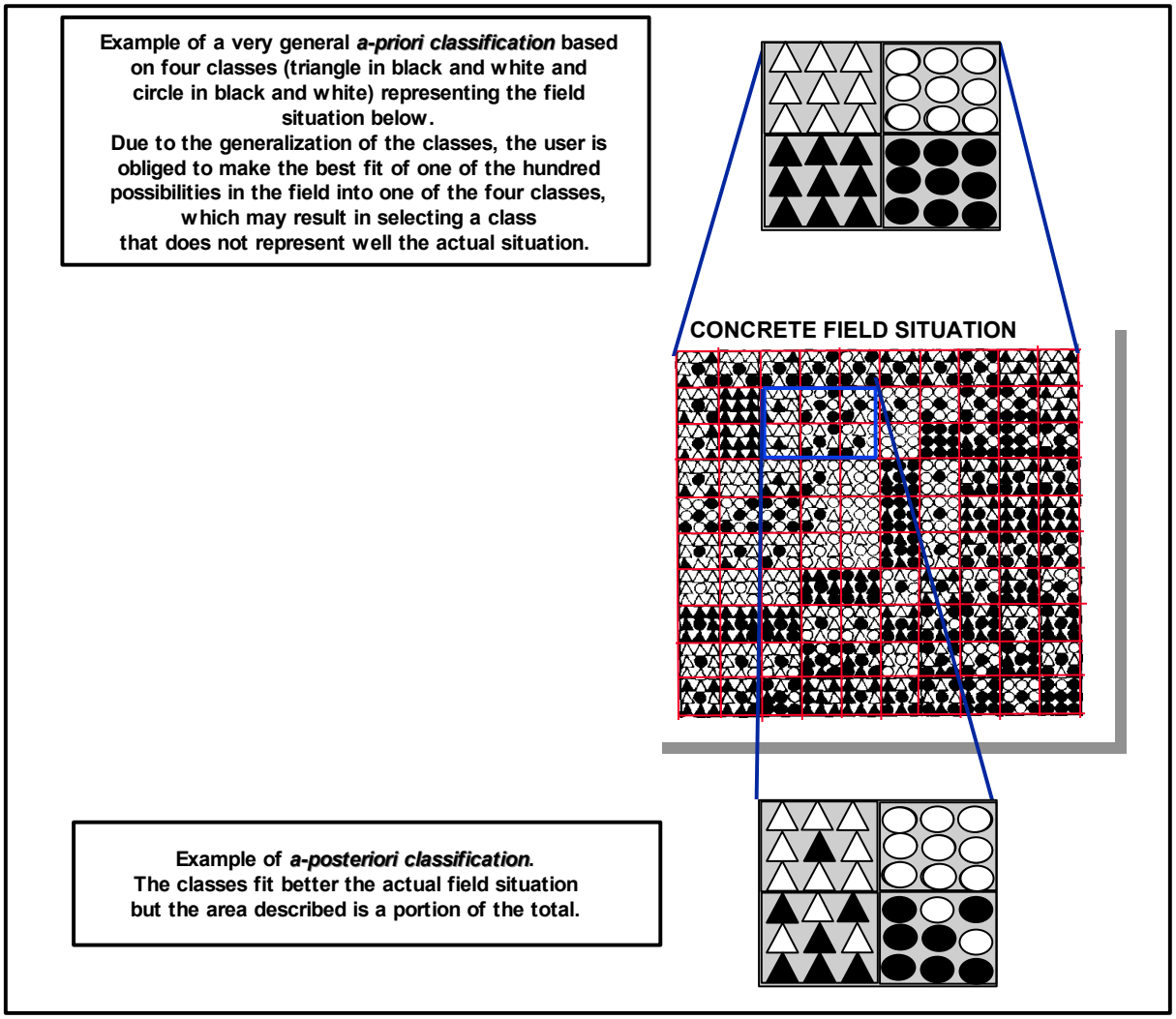
1.4 *A PRIORI* AND *A POSTERIORI* SYSTEMS

Classification can be done in two ways, that is either *a priori* or *a posteriori* (Figure 4). In an *a priori* classification system the classes are abstractions of the types actually occurring. The approach is based upon definition of classes before any data collection actually takes place. This means that all possible combinations of diagnostic criteria must be dealt with beforehand in the classification. Basically, in the field, each sample plot is identified and labelled according to the classification adopted. This method is used extensively in plant taxonomy and soil science (e.g., The Revised Legend of the Soil Map of the World (FAO, 1988) and the USDA Soil Taxonomy (United States Soil Conservation Service, 1975)). The main advantage is that classes are standardized independent of the area and the means used. The disadvantage, however, is that this method is rigid, as some of the field samples may not be easily assignable to one of the pre-defined classes.

A posteriori classification differs fundamentally by its direct approach and its freedom from preconceived notions. The approach is based upon definition of classes after clustering similarity or dissimilarity of the field samples collected. The Braun-Blanquet method, used in vegetation science (this is a floristic classification approach using the total species combination to cluster samples in sociological groups (Kuechler and Zonneveld, 1988)), is an example of such an approach. The advantage of this type of classification is its flexibility and adaptability compared to the implicit rigidity of the *a priori* classification. The *a posteriori* approach implies a minimum of generalization. This type of classification better

fits the collected field observations in a specific area. At the same time, however, because an *a posteriori* classification depends on the specific area described and is adapted to local conditions, it is unable to define standardized classes. Clustering of samples to define the classes can only be done after data collection, and the relevance of certain criteria in a certain area may be limited when used elsewhere or in ecologically quite different regions.

FIGURE 4.
Example of an *a priori* (above) and *a posteriori* (below) classification of a concrete situation in the field (adapted from Kuechler and Zonneveld, 1988).



2. THE CONCEPTUAL BASIS

2.1 PROBLEMS WITH CURRENT CLASSIFICATION SYSTEMS

Despite the necessity for a standard classification system, none of the current classifications has been internationally accepted (Danserau, 1961; Fosberg, 1961; Eiten, 1968; UNESCO, 1973; Mueller-Dombois and Ellenberg, 1974; Kuechler and Zonneveld, 1988; CEC, 1993; Duhamel, 1995). Often, the land cover classes are inappropriate for particular purposes (e.g., statistical or rural development needs), the scale is related to a specific purpose and the information is mostly obsolete. Furthermore, factors are often used in the classification system which result in a undesirable mixture of potential and actual land cover (e.g., including climate as a parameter). The reasons why none of the current classifications could serve as a reference system are manifold, as will be explained below.

2.1.1 Purpose

A proportion of the existing classifications are either vegetation classifications (e.g., Danserau, 1961; Fosberg, 1961; Eiten, 1968; UNESCO 1973; Mueller-Dombois and Ellenberg, 1974; Anderson *et al*., 1976; Kuechler and Zonneveld, 1988), broad land cover classifications, or systems related to the description of a specific feature (e.g., agricultural areas). Thus, they are limited in their capacity to define the whole range of possible land cover classes. An illustration is the UNESCO Vegetation Classification (designed to serve primarily for vegetation maps at a scale of 1:1 000 000), which considers only natural vegetation, while all other vegetated areas, such as cultivated areas and urban vegetated areas, are ignored. Other vegetation classifications, even if they consider agricultural areas, do not describe these classes with the same level of detail as used for the natural vegetation ones. In contrast, systems used to describe agricultural areas give very few details in their description of natural vegetation.

Many systems have been developed for a certain purpose, at a certain scale, and using a certain data type (e.g., the IGBP-DISCover global 1 km data set based on the National Oceanic and Atmospheric Administration – Advanced Very High Resolution Radiometer (NOAA-AVHRR)). Hence the derived classes are strictly dependent on the means used (e.g., in the previous example the classes will be only those that can be detected using NOAA).

Many current classification systems are not suitable for mapping, and subsequent monitoring purposes. The use of the type of diagnostic criteria and their hierarchical arrangement to form a class is very often in conflict with the ability to define a clear boundary between two classes. For monitoring, land cover changes take two forms: conversion from one category to another (e.g., from forest to grassland), and modification of condition within one category (e.g., from cultivated area to intensively cultivated area). The broader and fewer the categories used to describe land cover, the fewer the instances of conversion from one to another. If land cover classes are as broad as “forest and woodland”, “arable land” and “permanent meadows and pastures” (from the FAO Production Yearbook) then forest fragmentation, a shift from rainfed to irrigated cultivated areas and less dense grass cover due to overgrazing will not register as conversion nor as modification. A multi-user-oriented classification system should capture both.

2.1.2 Consistency

In most current classifications, the criteria used to derive classes are not systematically applied. Often, the use of different ranges of values depends on the importance given by the user to a particular feature (e.g., in many systems the cover ranges to distinguish tree-dominated areas are many, whereas only one single cover range is used to define shrub- or grass- dominated areas).

In some classifications the class definition is imprecise, ambiguous or absent. This means that these systems fail to provide internal consistency (e.g., the frequency with which classes in the CORINE (Co-ordination of Information on the Environment) Land Cover system overlap with other classes elsewhere in the same classification)(CEC, 1993).

In most systems, the full combination of diagnostic elements describing a class is not considered (e.g., a system which describes vegetation with the diagnostic criteria of three ranges of cover matched with three ranges of height must consistently apply these ranges for all life forms considered). The reason why most systems fail in application of this basic classification rule is that the entire set of permutations of the possible classifiers would lead to a vast number of classes which cannot be handled with the current methods of class description (e.g., in the example above, if there were 10 classes of each, the result would be 100 combinations). Therefore, the current systems often leave gaps in the systematic application of the used diagnostic criteria.

Very often the systems contain a number of classes, which due to their interrelation and hierarchical structure, appear to be a proportion of a broader set of classes. Thus, these types of systems are mere legends. The characteristic of legends is that only a proportion or subset of the entire range of possible classes is described. Such legends have the disadvantage that the user cannot refer back to a classification system, which precludes comparisons with other systems.

Threshold values are very often derived from knowledge of a specific geographic area, so that elsewhere the class boundary definition between two classes may become unclear, that is with overlaps or gaps. In these cases any comparisons will be impossible or inaccurate.

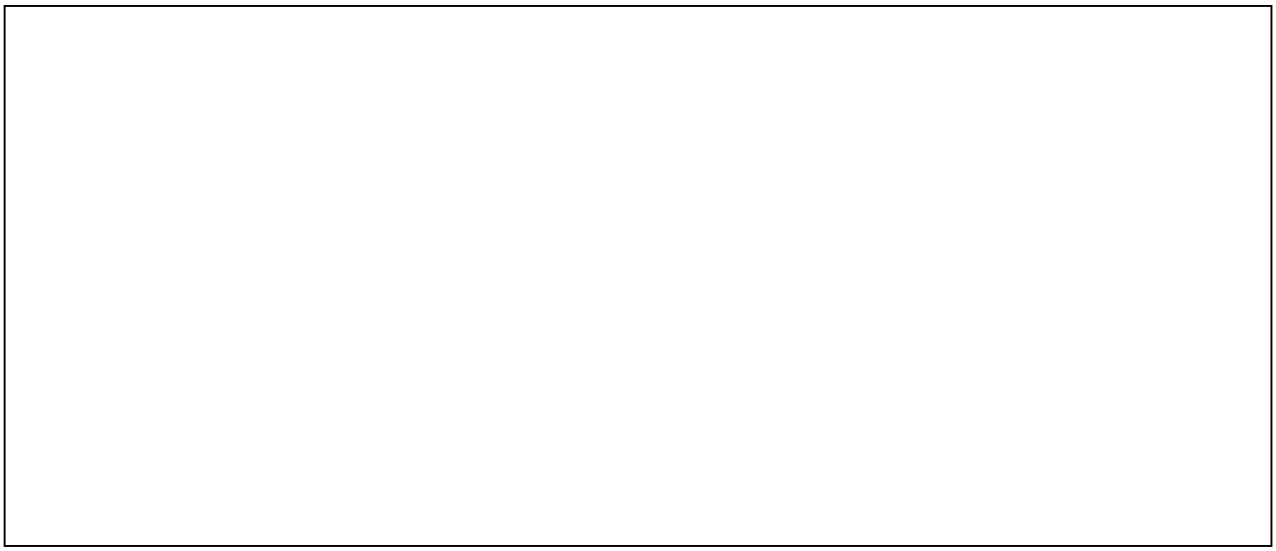
2.1.3 The Underlying Common Principle

An underlying common principle has often not been defined in land cover classification. A mixture of different features is used to define a class, especially features such as climate, geology, soil type and landform (thus, in "tropical rain forest" the term "tropical", which is usually climate related, is used to describe a certain floristic composition). Features such as climate, geology and landform influence land cover but are not *inherent features* of it. This type of combination is frequently found and is often applied in an irregular way without any hierarchy. This may lead to confusion in the definition of the class.

Classification of vegetation using the diagnostic criteria of “height” and “cover” will lead to a different perspective of the same feature in comparison with the use of “leaf phenology” and “leaf type” (Figure 5). It is therefore important to come to a basic understanding of the criteria to be used as underlying principles for land cover description.

FIGURE 5.

Example of description of a land cover using a different underlying principle.

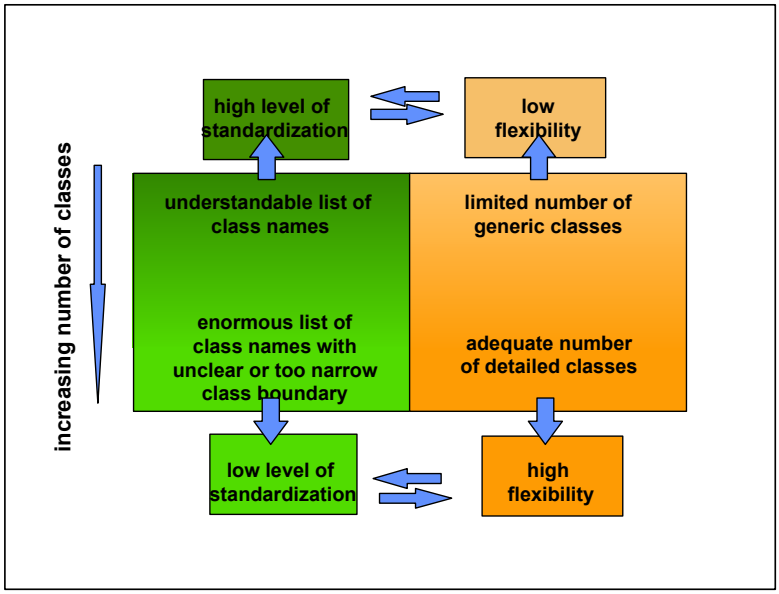


2.1.4 *A priori* classification systems

Often an *a priori* classification system is used in which classes are arranged. However, the use of such a classification assumes that all possible classes any user may derive, independent of scale and tools used, are included in the system. Having all classes pre-defined in the system is the intrinsic rigidity of an *a priori* classification system. The advantage of such a system is mainly that it is the most effective way to produce standardization of classification results between user-communities. The disadvantage is that to be able to describe consistently any land cover occurring anywhere in the world, one needs an enormous amount of pre-defined classes. Such a system should be flexible in the sense that any occurring land cover can be accommodated. How can one introduce this type of flexibility while using the “classical” approach of class names and descriptions?

By increasing the number of classes in an *a priori* system, the problem arises of how the users will find their way through a "jungle" of class names (Figure 6). Furthermore, this situation aggravates standardization, namely that every user may have a slightly different opinion on how to interpret some classes because the class boundary definitions between classes will be based on very slight differences. The wrong, or different, designation of the same land cover feature to different classes will affect this standardization process that is one of the chief objectives of the classification system. Ultimately, the attempt to harmonize will fail. The *a priori* classification approach appears to be a vicious circle: the attempt to create this type of classification as a tool for standardization obliges one to fit the enormous variety of occurring land cover in a limited number of more generic classes, while the endeavour to create more classes increases the danger of having a lack of standardization, the very basic principle used as starting point.

FIGURE 6.
Problem of the current *a priori* classifications in relation to their flexibility.



The above illustrates that there is not as much compatibility between classification systems, or between classification and legend, as may be desired. There are numerous inconsistencies in definition of classes, class boundaries, in the use of threshold values, etc. However useful the current classifications may be, these factors limit the possibility of the use of such classification results by a large audience for a broad range of applications.

In the context of developing a new system, it is fundamental to identify the criteria to which any reference classification, to the extent possible, should adhere (Box 1).

Box 1. General criteria for a reference classification.

The reference classification should be:

- *comprehensive, scientifically sound* and *practically oriented*;
- *meet the needs of a variety of users* (neither single-project oriented nor taking a sectoral approach); users can use just a sub-set of the classification and develop from there according to their own specific needs;
- potentially *applicable as a common reference system*, and facilitate comparisons between classes derived from different classifications;
- be a *flexible* system, which can be used at different scales and at different levels of detail allowing cross-reference of local and regional with continental and global maps without loss of information;
- *able to describe the complete range of land cover features* (e.g., forest and cultivated areas as well as ice and bare land, etc.), with clear class boundary definition that are unambiguous and unique;
- adapted to fully describe the whole variety of land cover types with the *minimal set of classifiers* necessary (the less classifiers used in the definition, the less the error expected and the less time and resources necessary for field validation); and
- based on a *clear and systematic description of the class*, where the diagnostic criteria used to define a class must be clearly defined, with pure land cover criteria distinct from environmental criteria (e.g., climate, floristic and altitude), as the latter influence land cover but are not inherent features.

2.2 THE BASIS FOR A NEW APPROACH

2.2.1 The Definition Adopted for Land Cover

The common integrated approach adopted here defines land cover as *the observed (bio)physical cover on the earth's surface* (see Section 1.1, above), but, in addition, it is emphasized that land cover must be considered a geographically explicit feature which other disciplines may use as a geographical reference (e.g., for land use, climatic and ecological studies).

Land is a basic source of mass and energy throughput in all terrestrial ecosystems, and land cover and land use represent the integrating elements of the resource base. Land cover, being the expression of human activities, changes with modifications in these activities. Therefore, land cover as a geographically explicit feature can form a reference basis for other disciplines.

2.2.2 A New Approach to Classification

Increasing flexibility while maintaining mapability

To create a standardized, hierarchical, consistent, *a priori* classification system containing systematic and strict class boundary definitions implies the basic requirement of having to build flexibility into the classification system. In this context, flexibility has different meanings. First of all, flexibility should address the potential for the classification system to describe enough classes to cope with the real world. At the same time, however, flexibility should adhere to strict class boundary definitions that should be unambiguous and clear. In addition, the classes in such a system should be as neutral as possible in the description of a land cover feature in order to answer to the needs of a wide variety of end-users and disciplines.

Many current classification systems are not generally suitable for mapping, and subsequent monitoring, purposes. The integrated approach requires clear distinction of class boundaries. Furthermore, the use of diagnostic criteria and their hierarchical arrangement to form a class should be a function of the *mapability*, that is the ability to define a clear boundary between two classes. Hence, diagnostic criteria should be hierarchically arranged in order to assure at the highest levels of the classification a high degree of geographical accuracy.

How does one increase the classification system's flexibility while maintaining the principle of mapability and aiming at standardization? These prerequisites can only be accomplished if the classification has the possibility of generating a high number of classes with clear boundary definitions. In other words, it should be possible to delineate a large number of classes in order to suit the enormous variation of land cover features, while maintaining the clear distinction of class boundaries. In current classification systems this possibility is hampered by the manner in which these classifications are set up. Differences between classes can only be derived from class descriptions. Therefore, it would be very difficult for the user to distinguish between such classes just based upon class names or unsystematic descriptions, as is the case with most of the current classification systems.

Basic principle

One of the basic principles adopted in the new approach is that a given land cover class is defined by the combination of a set of independent diagnostic attributes, the so-called *classifiers*. The increase of detail in the description of a land cover feature is linked to the increase in the number of classifiers used. In other words, the more classifiers added, the

more detailed the class. The class boundary is then defined either by the different amount of classifiers, or by the presence of one or more different types of classifiers. Thus, emphasis is no longer on the class name, but on the set of classifiers used to define this class.

Issues impeding application of the new approach

The straightforward application of this condition is hampered by two main factors. First, land cover should describe the whole observable (bio)physical environment and therefore deals with a heterogeneous set of classes. Obviously, a forest is best defined using a set of classifiers which differ from those to describe snow-covered areas. Instead of using the same set of classifiers to describe such heterogeneous features, in the new approach the classifiers are tailored to each land cover feature. According to the general concept of an *a priori* classification, it is fundamental to the system that all the combinations of the classifiers must be created in the system. By tailoring the set of classifiers to the land cover feature, all combinations can be made without having a tremendous number of theoretical but redundant combinations of classifiers. Secondly, two distinct land cover features, having the same set of classifiers to describe them, may differ in the hierarchical arrangement of these classifiers in order to ensure a high mapability.

2.3 LAND COVER CLASSIFICATION SYSTEM DESIGN CRITERIA

Land cover classes are defined by a string of classifiers, but due to the heterogeneity of land cover, and with the aim of achieving a logical and functional hierarchical arrangement of the classifiers, certain design criteria have been applied.

The Land Cover Classification System (LCCS) has been designed with two main phases (Figure 7):

An initial *Dichotomous Phase*, in which eight major land cover types are defined:

- Cultivated and Managed Terrestrial Areas
- Natural and Semi-Natural Terrestrial Vegetation
- Cultivated Aquatic or Regularly Flooded Areas
- Natural and Semi-Natural Aquatic or Regularly Flooded Vegetation
- Artificial Surfaces and Associated Areas
- Bare Areas
- Artificial Waterbodies, Snow and Ice, and
- Natural Waterbodies, Snow and Ice.

This is followed by a subsequent so-called *Modular-Hierarchical Phase,* in which land cover classes are created by the combination of sets of pre-defined classifiers. These classifiers are tailored to each of the eight major land cover types.

The tailoring of classifiers in the second Phase allows the use of most appropriate classifiers to define land cover classes derived from the major land cover types and at the same time reduces the likelihood of impractical combinations of classifiers. This results in a land cover class defined by:

- a *Boolean formula* showing each classifier used (all classifiers are coded);
- a *unique number* for use in Geographical Information Systems (GIS); and

- a *name* which can be the standard name as supplied or a user-defined name.

TABLE 1.
Distinction at the main Dichotomous level and the second level.

Classifiers used	Land Cover Class Name and Description
DICHOTOMOUS PHASE: INITIAL-LEVEL DISTINCTION	
Presence of Vegetation: *Primarily vegetated*	A. Primarily Vegetated Areas: This class applies to areas that have a vegetative cover of at least 4% for at least two months of the year. This cover may consist of the life forms *Woody* (Trees, Shrubs), *Herbaceous* (Forbs, Graminoids) or a combination of them, or consist of Lichens/Mosses (only when other life forms are absent). A separate cover condition exists for Lichens/Mosses that can be only applied if this life form contributes at least 25% to the total vegetative cover (see Glossary).
Presence of Vegetation: *Primarily non-vegetated*	B. Primarily Non-Vegetated Areas: This class includes areas that have a total vegetative cover of less than 4% for at least 10 months of the year, or an absence of Woody or Herbaceous life forms and with less than 25% cover of Lichens/Mosses
DICHOTOMOUS PHASE: SECOND-LEVEL DISTINCTION	
Primarily vegetated Edaphic Condition: *Terrestrial*	A1. Terrestrial Primarily Vegetated Areas: The vegetation is influenced by the edaphic substratum.
Primarily non-vegetated Edaphic Condition: *Terrestrial*	B1. Terrestrial Primarily Non-Vegetated Areas: The cover is influenced by the edaphic substratum.
Primarily vegetated Edaphic Condition: *Aquatic or regularly flooded*	A2. Aquatic or Regularly Flooded Primarily Vegetated Areas: The environment is significantly influenced by the presence of water over extensive periods of time. The water is the dominant factor determining natural soil development and the type of plant communities living on its surface. Includes marshes, swamps, bogs and all areas where water is present for a substantial period regularly every year. This class includes floating vegetation.
Primarily non-vegetated Edaphic Condition: *Aquatic or regularly flooded*	B2. Aquatic or Regularly Flooded Primarily Non-Vegetated Areas: The environment is significantly influenced by the presence of water over an extensive period of time each year.

TABLE 2.

Distinction at the third level of the Dichotomous Phase into eight major land cover types.

DICHOTOMOUS PHASE: TERTIARY-LEVEL DISTINCTION	
Primarily vegetated Terrestrial Artificiality of Cover: *Artificial/managed*	A11. Cultivated and Managed Terrestrial Areas: This class refers to areas where the natural vegetation has been removed or modified and replaced by other types of vegetative cover of anthropogenic origin. This vegetation is artificial and requires human activities to maintain it in the long term. In between the human activities, or before starting crop cultivation, the surface can be temporarily without vegetative cover. Its seasonal phenological appearance can be regularly modified by humans (e.g., tillage, harvest, and irrigation). All vegetation that is planted or cultivated with an intent to harvest is included in this class (e.g., wheat fields, orchards, rubber and teak plantations).
Primarily vegetated Terrestrial Artificiality of Cover: *(Semi-)natural*	A12. Natural and Semi-Natural Vegetation: Natural vegetated areas are defined as areas where the vegetative cover is in balance with the abiotic and biotic forces of its biotope. Semi-natural vegetation is defined as vegetation not planted by humans but influenced by human actions. These may result from grazing, possibly overgrazing the natural phytocenoses, or else from practices such as selective logging in a natural forest whereby the floristic composition has been changed. Previously cultivated areas which have been abandoned and where vegetation is regenerating are also included. The secondary vegetation developing during the fallow period of shifting cultivation is a further example. The human disturbance may be deliberate or inadvertent. Hence semi-natural vegetation includes vegetation due to human influences but which has recovered to such an extent that species composition and environmental and ecological processes are indistinguishable from, or in a process of achieving, its undisturbed state. The vegetative cover is not artificial, in contrast to classes A11 and A24, and it does not require human activities to be maintained in the long term.
Primarily vegetated Aquatic or Regularly Flooded Artificiality of Cover: *Artificial/managed*	A23 Cultivated Aquatic or Regularly Flooded Areas: This class includes areas where an aquatic crop is purposely planted, cultivated and harvested, and which is standing in water over extensive periods during its cultivation period (e.g., paddy rice, tidal rice and deepwater rice). In general, it is the emerging part of the plant that is fully or partly harvested. Other plants (e.g., for purification of water) are free-floating. They are not harvested but they are maintained. This class excludes irrigated cultivated areas.
Primarily vegetated Aquatic or Regularly Flooded Artificiality of Cover: *(Semi-)natural*	A24. Natural and Semi-Natural Aquatic or Regularly Flooded Vegetation: This class describes areas which are transitional between pure terrestrial and aquatic systems and where the water table is usually at or near the surface, or the land is covered by shallow water. The predominant vegetation, at least periodically, comprises hydrophytes. Marshes, swamps, bogs or flats where drastic fluctuations in water level or high concentration of salts may prevent the growth of hydrophytes are all part of this class. The vegetative cover is significantly influenced by water and dependent on flooding (e.g., mangroves, marshes, swamps and aquatic beds). Occasionally-flooded vegetation within a terrestrial environment is not included in this class. *Natural Vegetated Aquatic* habitats are defined as biotopes where the vegetative cover is in balance with the influence of biotic and abiotic forces. *Semi-Natural Aquatic* vegetation is defined as vegetation that is not planted by humans but which is influenced directly by human activities that are undertaken for other, unrelated purposes. Human activities (e.g., urbanization, mining and agriculture) may influence abiotic factors (e.g., water quality), affecting species composition. Furthermore, this class includes vegetation that developed due to human activities but which has recovered to such an extent that it is indistinguishable from its former state, or which has built up a new biotope which is in balance with the present environmental conditions. A distinction between Natural and Semi-Natural Aquatic Vegetation is not always possible because human activities distant to the habitat may create chain reactions which ultimately disturb the aquatic vegetative cover. Human activities may also take place deliberately to compensate for effects as noted above with the aim of keeping a “natural” state.

Classifiers used	Land Cover Class Name and Description
Primarily non-vegetated Terrestrial Artificiality of Cover: *Artificial/managed*	B15. Artificial Surfaces and Associated Areas: This class describes areas that have an artificial cover as a result of human activities such as construction (cities, towns, transportation), extraction (open mines and quarries) or waste disposal.
Primarily non-vegetated Terrestrial Artificiality of Cover: *(Semi-)natural*	B16. Bare Areas: This class describes areas that do not have an artificial cover as a result of human activities. These areas include areas with less than 4% vegetative cover. Included are bare rock areas, sands and deserts.
Primarily non-vegetated Aquatic or Regularly Flooded Artificiality of Cover: *Artificial/managed*	B27. Artificial Waterbodies, Snow and Ice: This class applies to areas that are covered by water due to the construction of artefacts such as reservoirs, canals, artificial lakes, etc. Without these the area would not be covered by water, snow or ice.
Primarily non-vegetated Aquatic or Regularly Flooded Artificiality of Cover: *(Semi-)natural*	B28. Natural Waterbodies, Snow and Ice: This class refers to areas that are naturally covered by water, such as lakes, rivers, snow or ice. In the case of rivers, the lack of vegetation cover is often due to high flow rates and/or steep banks. In the case of lakes, their geological origin affects the life conditions for aquatic vegetation. The following circumstances might cause water surfaces to be without vegetation cover: depth, rocky basins, rocky and/or steep shorelines, infertile washed-in material, hard and coarse substrates.

2.3.1 Dichotomous Phase

As stated above, a dichotomous key is used at the main level of classification to define the major land cover classes (Figure 7). Each major land cover type is defined as shown in Tables 1 and 2.

Three classifiers are used in the Dichotomous Phase, namely *Presence of Vegetation*, *Edaphic Condition* and *Artificiality of Cover*. These three classifiers have been hierarchically arranged, although independent of this arrangement the same eight major land cover types would be keyed out. The hierarchical arrangement is thus not important in this Phase, but is a guiding principle in the subsequent Modular-Hierarchical Phase.

2.3.2 Modular-Hierarchical Phase

In this phase the creation of the land cover class is given by the combination of a set of pre-defined pure land cover classifiers. This set of classifiers is different for each of the eight main land cover types. This difference is due to the tailoring of the classifiers to their respective type (Figure 8).

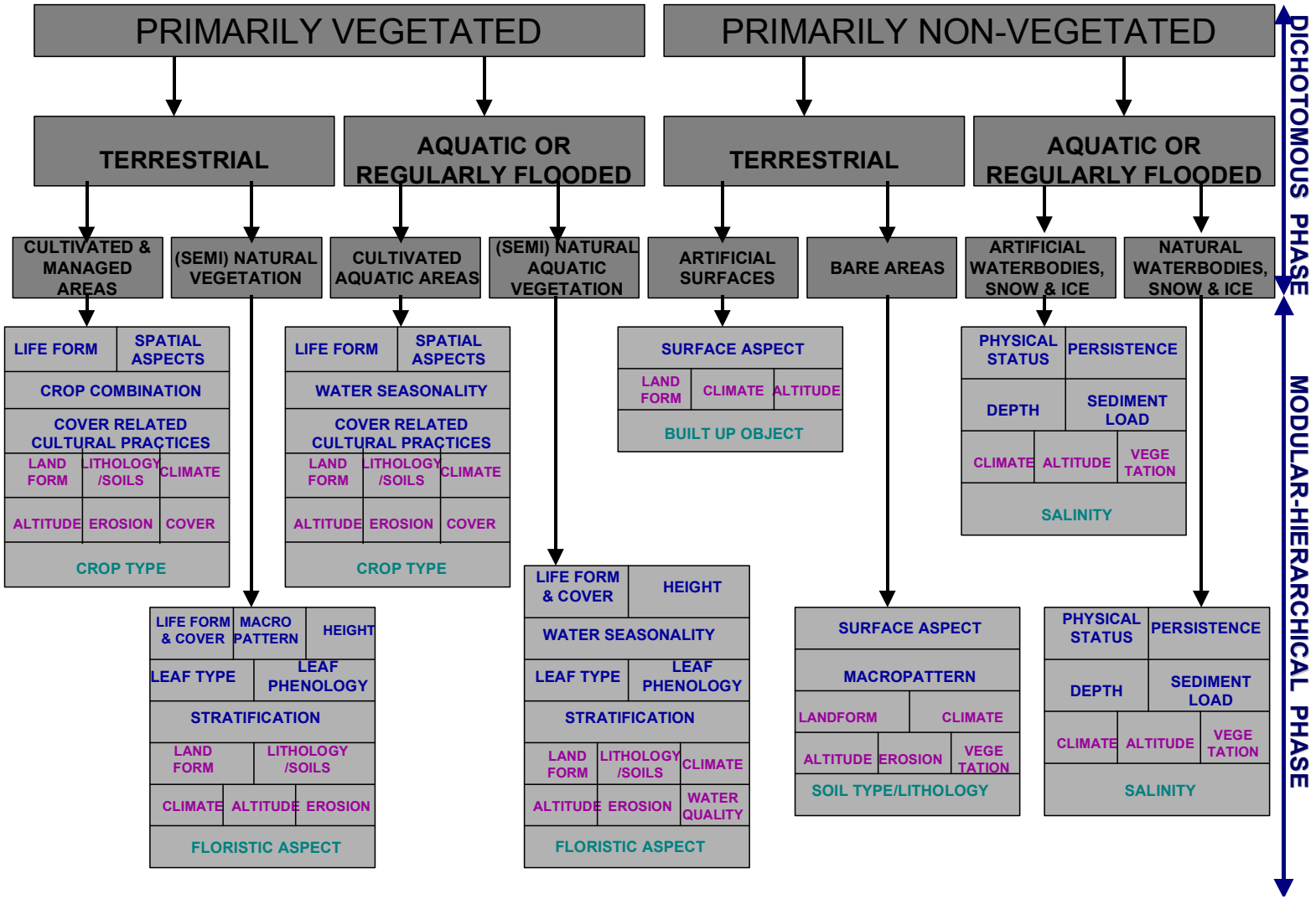


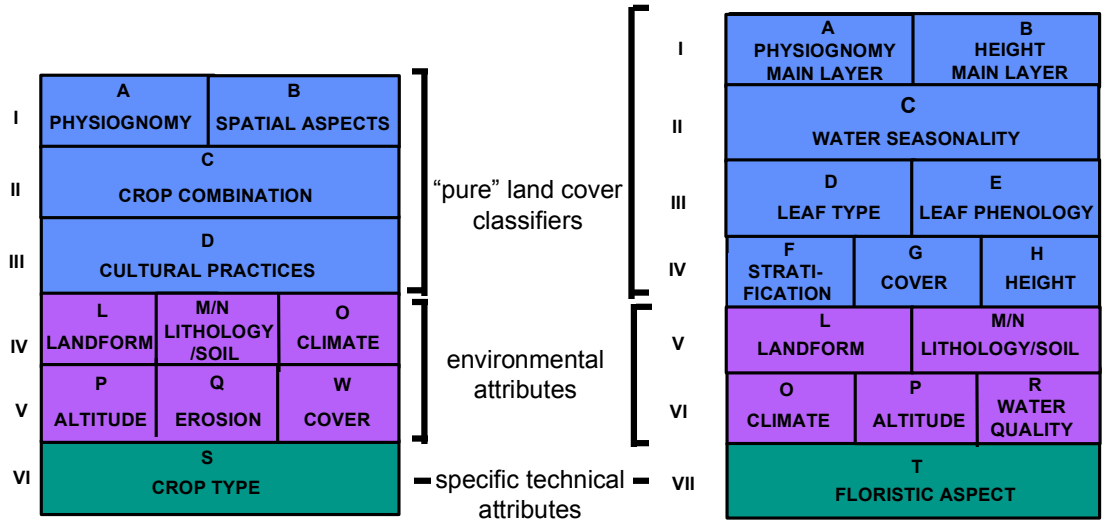
FIGURE 7. **Overview of the Land Cover Classification System, its two phases and the classifiers.**

These pure land cover classifiers can be combined with so-called *attributes* for further definition. Two types of attributes, which form separate levels in the classification, are distinguished (Figure 8 for two examples):

- *Environmental Attributes*: these attributes (e.g., climate, landform, altitude, soils, lithology and erosion) influence land cover but are not inherent features of it and should not be confused with "pure" land cover classifiers. These attributes can be combined in any user-defined order; and

- *Specific Technical Attributes*: these attributes refer to the technical discipline. For (Semi-)Natural Vegetation, the *Floristic Aspect* can be added (the method how this information was collected as well as a list of species); for Cultivated Areas, the *Crop Type* can be added either according to broad categories commonly used in statistics or by crop species; and for Bare Soil, the *Soil Type* according to the FAO/UNESCO Revised Soil Legend can be added). These attributes can be added freely to the pure land cover class without any conditions.

FIGURE 8.
The Modular-Hierarchical Phase: example of tailoring of the classifiers and attributes for the "Cultivated and Managed Terrestrial Lands" (left) and "Natural and Semi-Natural Aquatic or Regularly Flooded Vegetation" (to the right).



The user is obliged to start with the pure land cover classifiers. However, at any time the user can stop – dependent upon the level of detail required – and derive a land cover class (Table 3). Further definition of this class can be achieved by adding a single or a combination of any of the other types of attributes. These attributes are not hierarchically ordered and selection of them will generate a separate coded string.

Because the classification is suitable for mapping purposes, the system gives high priority to "mapability", the user needs to follow specific rules:

- A higher level of land cover classifier must be used before going to a lower level (because mapability is high at higher levels and decreases with lower levels).

- Within certain levels of land cover classifier there are pure land cover classifiers, and a further subdivision of them, the *modifiers*, which refine the classifier further but are optional and do not necessarily need to be determined.

- All land cover classifiers at one level of the classification have to determined before the system allows one to go to the next level.

- At any time inside a land cover classifier level the user can stop, and a mutually exclusive class is defined.

- All land cover classes defined in such way are hierarchically arranged in the Legend (see Legend Module).

- At any time the user can further define the land cover class using environmental or specific technical attributes, alone or in combination. These attributes will add a second, separate, code to the land cover class because they are not inherent features of land cover.

- A Boolean formula (i.e., a combination of the classifiers used), a unique code (numerical) and a name (nomenclature) define each land cover class.

TABLE 3.
Example of the formation of land cover classes.

Example "Natural and Semi-Natural Terrestrial Vegetation (A12)":

Classifiers Used:	Boolean Formula:	Standard Class Name:	Code:
Life Form & Cover	A3A10	Closed Forest	20005
Height	A3A10B2	High Closed Forest	20006
Spatial Distribution	A3A10B2C1	Continuous Closed Forest	20007
Leaf Type	A3A10B2C1D1	Broadleaved Closed Forest	20095
Leaf Phenology	A3A10B2C1D1E2	Broadleaved Deciduous Forest	20097
2nd Layer: LF, C, H	A3A10B2C1D1E2F2F5F7G2	Multi-Layered Broadleaved Deciduous Forest	20628
3rd Layer: LF, C, H	A3A10B2C1D1E2F2F5F7G2 F2F5F10G2	Multi-Layered Broadleaved Deciduous Forest With Emergents	20630

2.3.3. Concepts for the Primarily Vegetated Areas

There are different ways of making an orderly arrangement of the *Primarily Vegetated Areas*, with varying success according to region or purpose. Vegetation has a multitude of properties and features, and a certain degree of abstraction is required when classifying. However, agreement could be reached on selection of a relatively small number of diagnostic criteria to identify plant communities.

Plant communities, or phytocenoses, are characterized by two important features:

- all plant communities consist of *growth forms*; and
- all plant communities consist of *plant species*.

This applies to all phytocenoses on earth (Kuechler and Zonneveld, 1988). Growth forms (e.g., trees, shrubs, herbaceous, etc.) are so important that various vegetation scientists have used them as criteria for classification (Danserau, 1961; Mueller-Dombois and Ellenberg, 1974). The growth forms are distributed within the plant community in layers or *strata*. This stratification is common and the distinction of the individual strata is of fundamental importance when analysing the plant community. Plant communities are not limited to vertical arrangement into layers: they are also arranged horizontally (i.e., the horizontal spatial distribution).

Thus, when observing plant communities and considering their growth forms, two factors are fundamental:

- *physiognomy,* the overall appearance of the vegetation; and
- *vegetation structure* which is defined as "the spatial distribution pattern of growth forms in a plant community" (Kuechler and Zonneveld, 1988). The structure, then, describes the individual strata, usually characterized by height and density or coverage of the respective growth forms.

At the same time, a plant community consists of *taxa* (botanical species) that are usually unevenly distributed insofar as some may be common, or dominant, while others are less conspicuous. The component taxa can be used to describe the plant community as well as the structure. A description using taxa is called the *floristic composition* of the plant community. The floristic composition usually contains all species, though it is unusual to include the rare or incidental ones.

The various existing classification systems have emphasized one or other of the above (e.g., physiognomic-structural systems; floristic systems; physiognomic-floristic systems). There is no doubt that a full description of a plant community must consider both physiognomic-structural and floristic aspects. A phytocenose can have the same structural aspect but different floristic composition, as well as the same floristic composition but a different structural aspect. However, problems arise when attempting to incorporate both types of information in a single classification system.

In the Land Cover Classification System, *Natural and Semi-Natural Vegetation*, in both the *Terrestrial Areas* (A12) and *Aquatic or Regularly Flooded Areas* (A24), are classified using a pure physiognomic-structural method. The aspects considered are, thus: (1) physiognomy; (2) vertical and horizontal arrangement; (3) leaf type; and (4) leaf phenology of plants. This concept has been adopted with the conviction that only a pure structural representation of vegetation is able to incorporate, without any confusion of terms, floristic aspects of vegetation as well as environmental attributes (e.g., landform, climate, altitude, etc.). The

proposed classification allows the user to add freely these attributes at any level of the created structural land cover class.

Users not familiar with classical vegetation classification and mapping (Eiten, 1968; UNESCO, 1973; White, 1983; Kuechler and Zonneveld, 1988) or ecological studies should be able to build up a scientifically sound vegetation classification by following the Land Cover Classification System. This will avoid the separation between classical vegetation classification and land cover classification. A variety of users should be able to apply the results of the classification, even those who are not specialized in vegetation mapping.

The physiognomic-structural approach selected for classification of vegetated areas in a land cover classification system poses a challenge with regard to classification of vegetated areas other than (semi-)natural vegetated areas, namely cultivated and urban vegetated areas. These managed vegetated areas are also characterized by plant communities having growth forms and taxa, a structure and a floristic composition. Therefore, the physiognomic-structural approach adopted is equally applicable to such areas. Using the same approach to describe and classify this type of area at a certain level of detail has the advantage that all *Primarily Vegetated Areas* can be compared.

2.3.3.1 Natural and Semi-Natural Vegetation (A12 and A24)

General rules for classification

Before starting to use the classifiers, the user has to take into account some basic rules governing the concepts of classification of (Semi-)Natural Vegetation, namely:

- the definition of *Life Form*; and
- the definition of *dominance*

These two main aspects are very important and must be carefully determined because in the software the determination of Main *Life Form* has consequences for the selections available at subsequent levels. Certain choices at a high level of the system may disable choices at lower levels.

- *Life Form* of a plant is defined by its physiognomic aspect. This is the case when *Woody* plants, subdivided into *Trees* and *Shrubs*, are distinguished from *Herbaceous* plants, subdivided into *Forbs* and *Graminoids*, and *Lichens/Mosses*.

- A condition of *Height* is applied to separate *Trees* from *Shrubs*: woody plants higher than 5 m are classified as *Trees*. In contrast, woody plants lower than 5 m are classified as *Shrubs*. This general rule is subject to the following exception: a woody plant with a clear physiognomic aspect of trees can be classified as *Trees* even if the *Height* is lower than 5 m but more than 3 m. In this case, a subcondition of physiognomic aspect is added to the *Height* condition.

These are the limits recommended for Life Form distinction, but exceptions are allowed:

- Plants essentially herbaceous but with a woody appearance (e.g., bamboos and ferns) are classified as *Trees* if the height is more than 5 m, and as *Shrubs* if the height is less than 5 m.

These are the recommended thresholds for Life Form characterization.

Concerning the concept of dominance, two criteria need to be considered:

- The main criteria is the **uppermost canopy layer**. This means that the dominant layer goes from *Tree* canopy to *Shrub* to *Herbaceous/Forbs/Graminoids*.

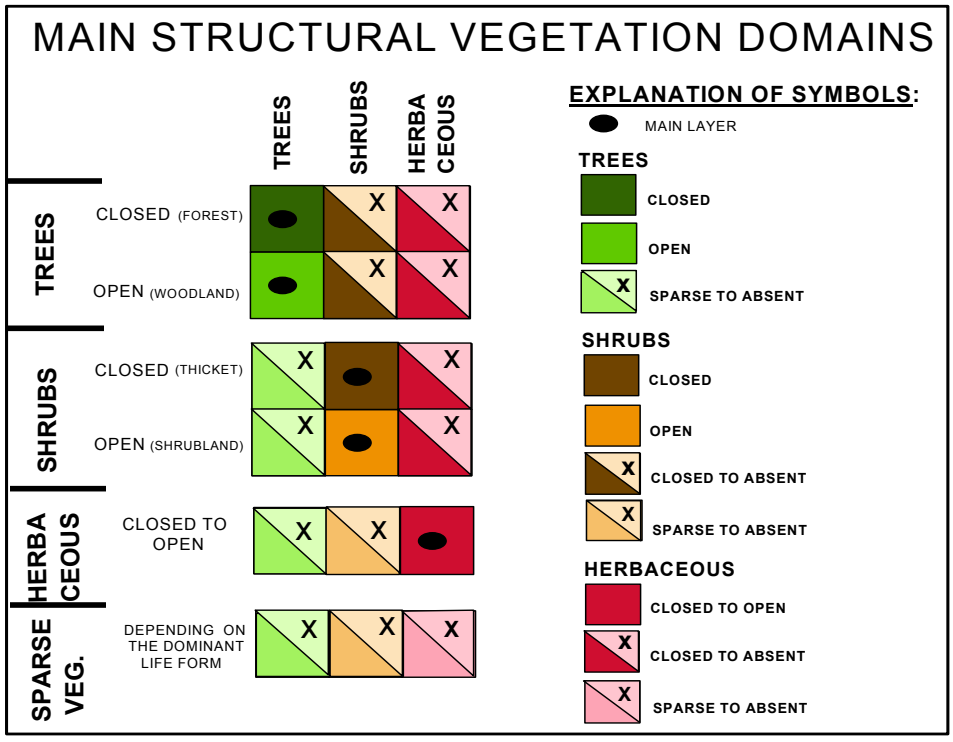
- This general rule is subject to a **sub-condition of *Cover***: it is only valid if the dominant Life Form has a Cover either *Closed* or *Open*. If the Life Form is *Sparse,* the dominance goes to another Life Form that has a Closed or Open cover (Figure 9).

When the user has decided these two main aspects, the building of classes can start. The rules explained above show that in order to determine a (Semi-)Natural Vegetation class, a minimum of three classifiers need to be selected:

- Life Form
- Cover
- Height

These are the minimum elements required to form a *Natural* or *Semi-Natural* Vegetated land cover class, for both *Terrestrial* and *Aquatic or Regularly Flooded Areas*. Because *Height* (in its standard denotation) is automatically linked to the Life Form chosen, the classifiers needing to be determined are actually two: *Life Form* and *Cover*.

FIGURE 9.
Main Structural Vegetation Domains (Di Gregorio and Jansen, 1996a).



A. Life Form and Cover

A *Life Form* is a group of plants having certain morphological features in common (Kuechler and Zonneveld, 1988). According to the quality of the main axis or shoots, a further distinction is made into *Woody* or *Herbaceous*. For further subdivision, the following growth form criteria can be applied:

- *Branching symmetry*, subdividing Trees and Shrubs; and
- *Herbaceous plant physiognomy*, subdividing *Forbs* from *Graminoids* (Strasburger et al., 1983; Kuechler and Zonneveld, 1988) and from *Lichens/Mosses*.

The full definitions and guidelines for application in the system are found in the Glossary of the software program, and as Appendix A here.

Cover can be considered as the presence of a particular area of the ground, substrate or water surface covered by a layer of plants considered at the greatest horizontal perimeter level of each plant in the layer (according to Eiten, 1968). A distinction is made between Closed (>(60 – 70) percent), Open (between (60 – 70) and (10 – 20) percent) and Sparse (below (10 – 20) percent but >1 percent). As herbaceous plants are seasonal in character, it is always assessed in terms of fullest development.

The reason for expressing cover in terms of ranges instead of absolute values is discussed in the relevant guidelines of the software program and in Appendix A here.

B. Height

The *Height* of a certain layer is measured from the ground to the average top of the life form that is being examined (Kuechler and Zonneveld, 1988). The fact that single plants of one synusia differ from the average height can be ignored, apart from the fact that they can form their own layer (e.g., the emergents of a rainforest that tower above the rest). The *Height* is classed as: Trees >30 – 3 m; Shrubs 3 – 0.3 m; and Herbaceous 3 – 0.03 m. Each class can be further subdivided.

The major *Height* classes are linked to the Life Form selected. These classes provide general information regarding height because, in the concept of the classification, this criterion has not been given a prevalent importance. The user can choose to remain at this generic level, or to go to the modifiers, whereupon the importance of height increases.

In the case of *Shrubs* or *Herbaceous* (Forbs or Graminoids) life forms, it is strongly recommended not to remain at the level of the standard definition of *Height*, if this is possible, but instead to select one of the modifiers. The ecological significance of these life forms can be strongly correlated with height (e.g., separation between low and tall herbs or between dwarf and high shrubs, especially concerning potential for grazing/rangeland).

C. Spatial Distribution or Macropattern

The next classifier that can be applied is the *Macropattern*. It is defined as the *horizontal spatial distribution of vegetation in a certain area*. It should not be confused with *Cover* because that defines the spatial arrangement of Life Forms (e.g., trees, shrubs, etc.). Macropattern describes the spatial arrangement of specific structural vegetation types (e.g., *Closed Forest*, *Closed Shrubs*). This classifier may seem unusual, but there are good reasons:

- Often the *Macropattern* reflects an ecological or an evolutionary aspect of vegetation (e.g., scattered vegetation in arid areas; agricultural encroachment inside forest areas; degradation due to overgrazing; etc.). In many classifications, one find terms that are extremely subjective, like "Degraded Forest" or similar. The present classification aims to be neutral in its land cover description without including ambivalent terminology. Therefore *Macropattern* is used as a neutral classifier to describe vegetation status;

- this classification has been built up for mapping purposes, therefore spatial distribution of land cover is an important aspect; and

- macropattern is easy detectable from remote sensing data (photographs and imagery), i.e., it has good "mapability."

Macropattern should thus be used to give supplementary ecological information (or to show a human-induced degradational aspect of natural vegetation). The user has the possibility of skipping this classifier if it is felt to be irrelevant.

The combinations between *Cover* and *Macropattern* are unrestricted (this is nevertheless only valid for *Closed* and/or *Open Cover,* as will be explained later) which means that, for instance, a Closed Tree formation (Closed Forest) can be either *Continuous* or *Fragmented* depending on its spatial distribution in the mapping unit.

Because of this dimensional aspect, *Macropattern* is linked with the mapping scale. This may seem a contradiction with the main classification concept explained above, namely that the elements of a classification system must be scale-independent. To determine *Macropattern*, one should refer to the overall appearance of a vegetation formation in a certain area in a homogeneous landscape. However, if one wants to be more precise or objective in the application of this classifier, some specific rules are given below to help the user who is not familiar with this concept in order to standardize the interpretation. Because we are dealing with the practical application of this concept in a cartographic context, the concepts of mixed units and minimum mapable areas will be used. These concepts are further described in Section 2.5.

A certain structural vegetation type has a continuous *Macropattern* if, inside the minimum mapable area, it covers more than 80 percent of the area.

A particular structural vegetation type would be considered a Fragmented *Macropattern* if inside the minimum mapable area it covers more than 20 percent but less than 80 percent. This situation is linked with the concept of mixed unit. Three cases are possible:

- The structural vegetation type (e.g., dense forest) covers more than 50 percent of the area and the other element (e.g., agricultural fields) covers less than 50 percent but more than 20 percent. In this case the resulting unit will be a mixed unit with the fragmented dense forest as the dominant one (e.g., fragmented dense forest/agricultural fields).

- The structural vegetation type (e.g., dense forest) covers less than 50 percent but more than 20 percent of the area. The other element (e.g., agricultural fields) covers more than 50 percent. In this case the class is also mixed, but the dominant class will be the agricultural fields (i.e., agricultural fields/fragmented dense forest).

- When a unit contains three elements (e.g., fragmented dense forest, agricultural fields and bare areas) the rules for mixed units should be applied (see Section 2.5). In this case it could be possible to have a structural vegetation type with a Fragmented *Macropattern* as single unit (e.g., fragmented dense forest, 70 percent; agricultural fields, 15 percent; and bare areas, 15 percent. As neither of the subsidiary elements reach a cover exceeding 20 percent, the unit must be considered a single mapping unit of fragmented dense forest). This is the only case when a structural vegetation type with Fragmented *Macropattern* must be considered as a single mapping unit. Even if theoretically possible, this case must be considered a very unusual one, and therefore should be avoided.

The *Continuous* or *Fragmented* classifiers are linked with the Cover, *Closed* or *Open* (e.g., Closed Continuous Forest, Closed Fragmented Forest, Continuous Woodland and

Fragmented Woodland). Fragmentation can be further subdivided into *Striped* or *Cellular* (e.g., the tiger bush in the Sahel, where Closed Shrubs are present in the interdunal areas, which can be represented as Fragmented (Striped) Closed Shrubs).

The *Parklike Patches* Macropattern is directly linked with the cover category *Sparse*. Basically, this is simply redundant information. When the user defines the cover of a certain life form to be Sparse, the only Macropattern available for this structural vegetation type is Parklike Patches.

The Macropattern concept is preferentially used for Woody Life Forms (Trees, Shrubs). Herbaceous Life Forms (Graminoids, Forbs) can have a Macropattern, but this is subordinated to the absence of Woody Life Forms. When linear patches of dense shrubs (typical of tiger bush) are present together with dense herbaceous vegetation filling the space between patches, one could have two different perspectives of this situation, either *Fragmented Shrubs/Herbaceous* or *Fragmented Herbaceous/Shrubs*. In the application of the Macropattern, the rule obliges the user to always give preference, to the Woody component. Macropattern can be applied to Herbaceous Life Forms only when there is no significant presence of Woody Life Forms (Trees, Shrubs). For instance, patches of dense herbaceous vegetation in sandy areas can be called fragmented herbaceous/sand.

A structural vegetation type is *Fragmented* when the size of the patches of the vegetation are between 1/15 and 1/2 of the minimum mapable unit. This rule is a very artificial one and should not be rigidly applied. Nevertheless, the rule assists the user by providing some reference indicator of what a Fragmented Macropattern should look like. If the patches become too small, at a certain level they could coincide with the life form itself, thus contradicting the basic rule explained above, namely that Macropattern describes the specific arrangement of structural vegetation types and must not be confused with the cover of the life form.

If all the above mentioned classifiers are determined, the user can enter the next level and add a new set of information.

C. Water Seasonality

For Aquatic or Regularly Flooded Natural and Semi-Natural Vegetation (A24), the second level classifier consist of *Water Seasonality*. This classifier can be considered as the type of persistence of the water at or near the surface. There are three subdivisions:

- *(Semi-)Permanent* (three months a year or more than a specific season)
- *Temporary* or *Seasonal* (less than three months a year or during a specific season); and
- *Waterlogged*.

D. Leaf Type and E. Leaf Phenology

This level consists of the classifiers *Leaf Type* and *Leaf Phenology*. It can be entirely skipped. This option is included to allow the user to opt for a basic physiognomic-structural vegetation classification. The choice of the dominant *Life Form* will disactivate a number of choices at this level as a consequence of the conditions of the classification.

The classifier Leaf Type is subdivided into:

- *Broadleaved*: referring to trees and shrubs of the botanical group Angiospermae, with the exception of ginkgo (*Ginkgo biloba*), which belongs to the Gymnospermae taxonomically.

- *Needleleaved:* referring to trees and shrubs of the botanical group Gymnospermae (Ford-Robertson, 1971) carrying typical needle-shaped leaves.

- *Aphyllous:* this category encompasses plants without any leaves and plants which apparently do not have leaves in the common sense. In the first case, photosynthesis takes place through other organs, such as stems, branches and twigs; in the latter case the leaves are very short-lived or extremely reduced, to scales and thorns. Characteristic genera are *Casuarina, Euphorbia, Tamarix* and many others mostly found in arid and semi-arid regions (Kuechler and Zonneveld, 1988).

Leaf Phenology is determined from the general behaviour of woody plants through the year. A distinction is made between evergreen and deciduous:

- *Evergreen:* perennial plants that are never entirely without green foliage (Ford-Robertson, 1971).

- *Deciduous*: perennial plants which are leafless for a certain period during the year (Ford-Robertson, 1971). Leaf shedding usually takes place simultaneously and in connection with the unfavourable season (UNESCO, 1973).

The modifiers *Semi-Deciduous, Semi-Evergreen* and *Mixed,* as well as *Perennial* and *Annual,* are explained in the Glossary.

F. Stratification or Layering

The user can describe up to three layers of stratification (including the main layer) for *Terrestrial Vegetation* (A12) and up to two layers in *Aquatic* or *Regularly Flooded Vegetation* (A24) (see Appendix B). The users may be disappointed by the limited number of layers at their disposal, but the classifier *Stratification* should contribute to the structural definition of a vegetation class. This means that this classifier must cover all the possible combinations with the main Life Form selected and its Cover (e.g., if we can have layering for Closed Trees, the same must be valid for Closed or Open Shrubs or Closed Graminoids, etc.). The layering is an active component of the class set-up; it is not a mere descriptive (optional and unsystematic) item of the class. The proposed classification allows the user to first build up a land cover class with the use of the classifier *Stratification* and, where more

detail is wanted, add a users' description to the standard one, which may contain information on any additional layers/strata.

Some limitations in the use of the classifier *Stratification* have been introduced in order to avoid irrelevant (from the structural point of view) class combinations. The following examples will further clarify this concept:

- "Tree Savanna" is clearly defined by two main elements: a Herbaceous vegetation layer and a Sparse Trees layer. Thus, the Stratification of the two elements Herbaceous and Tree layer is crucial for the definition of this class.

- "Closed Forest" is clearly defined by the element of a Closed Trees layer. Limitations have been introduced (as will be explained below) for this class in the use of Stratification. It is not possible, in this case, to determine the presence of a Herbaceous layer because the classification rules set up for the Layering allow the user only to determine sub-layers of Trees and/or Shrubs. The determination of a Herbaceous layer would not contribute to the main structural meaning of the class as defined at the first level. The element Herbaceous layer can be added as part of the user-defined description of the class (see Legend - Edit).

The limitations introduced, as shown in the two examples above, are to avoid introducing elements not crucial for the determination of the structural aspects of a land cover class. These elements can be added in the class description in the Legend (see *Legend - Edit*). These limitations have the practical purpose of reducing the number of possible combinations of classifiers, which otherwise could lead to the creation of an even larger number of classes that yet would have the same structural meaning. All limitations in use of *Stratification* are built into the software program.

From the practical point of view in the use of the Stratification concept, it is important to recognize that two possible types of Stratification exist:

(a) where the second stratum consists of the *same* Life Form as the main stratum (e.g., trees-trees and shrubs-shrubs); and

(b) where the second stratum consists of a *different* Life Form (e.g., trees-shrubs).

The second case is quite straightforward and does not present any difficulty in the selection of classifiers. The first case needs additional explanation. In the case of a dominant Life Form of Trees with a second stratum of Trees, it is important that these layers are clearly distinguishable from one another (e.g., a second strata of *Trees Emergent* over a *Closed Tree* canopy; where these emergents must not be part of the discontinuity of the Closed Tree canopy but clearly a distinct layer). The sub-condition of *Height* will pre-set the available choices of Height for second and/or third layers/strata (e.g., main stratum of *Closed Low Trees* (3-7 m), the emergents to be defined in the second stratum cannot have the same height (option 3-7 m therefore not available) because the *Sparse Trees* of the second layer have to be taller).

The *Height* parameter explained above depends on the Height value chosen for the main stratum; it is not applied if the general Height class is selected. If the user selects the general Height class for the main stratum, then for subsequent strata the general Height classes are the only options available.

The main conditions applied for Stratification/Layering are the following:

(a1) Forbs and Graminoids are considered always together as Herbaceous;

(a2) For Trees, three strata including the main, can be considered (e.g., a main Closed Tree layer with a second lower Closed to Open Tree layer and a third Sparse Tree layer of emergents is called a "Multi-Layered Forest With Emergents");

(a3) When the main stratum is Closed Trees or Open Trees and there is a second layer of Sparse Trees then the Height of the second layer must be higher, i.e. emergent. If they are lower they are not considered as an independent stratum;

(a4) For Shrubs the number of strata with the same Life Form is two, including the main strata;

(a5) For Herbaceous only one stratum is possible;

(a6) Lichens/Mosses are not described in the layering;

(a7) If the main stratum is Trees and the Cover is Open, then it is impossible to have the same Life Form with Cover Open To Closed with a different height as a second stratum (e.g., Open High Trees with Open Low Trees is impossible).

(a8) If the main stratum is Shrubs and the Cover is Closed or Open with the general option of Height, then it is impossible to have the same Life Form with Cover Open To Closed with a different height as a second stratum (e.g., Open High Shrubs with Closed To Open Low Shrubs is impossible). The only exception to this rule is when the second stratum consists of Dwarf Shrubs.

and

(b1) If the cover of the main stratum is Closed Trees or Closed Shrubs, then any Herbaceous layer is not considered or described (this can be added as a user-defined description);

(b2) Sparse Herbaceous is never considered as second layer except when the main layer is Sparse Trees or Sparse Shrubs (but it can be added as user-defined description);

(b3) If the main stratum is Shrubs or Herbaceous, only one layer of trees can be considered. This is linked with the criterion of dominance, as described earlier, because the Trees or Shrubs can be only Sparse;

(b4) Only two layers other than the main layer are considered for Terrestrial Vegetation (A12), and only one additional stratum for Aquatic or Regularly Flooded Vegetation (A24).

2.3.3.2 Cultivated and Managed Terrestrial Areas (A11 and A23)

Cultivated areas are often only described and classified by determining the crop species, the cultural practices and in some case land tenure information. This may result in descriptions like "rainfed agricultural area" or "state-owned rubber plantation." These descriptions are highly sectoral and do not address the needs of a wide variety of end-users. Another important aspect is that in the sectoral approaches the principle of having a high level of geographical accuracy is frequently lacking.

Description of agricultural areas in land cover terms should be exhaustive and neutral in the sense that the results may be used by many. Furthermore, these areas are Primarily Vegetated land cover types, thus their description should have a link to (semi-)natural vegetated land cover types at a certain level of detail (e.g., a user interested in trees because of the nesting prospects of a certain bird may not be directly interested in knowing if these trees are part of a crop or (semi-)natural vegetation). Furthermore, the focus should be on the definition of geographically well-defined classes, i.e., classes having a high mapability.

Therefore, the approach taken in order to enable a wide variety of users to employ the descriptions of cultivated areas is that of a basically physiognomic-structural classification. This means that at a high level of classification the cultivated area description is based on the structure of the vegetation, whereas at lower levels, with lower mapability, the focus is on description of the spatial and temporal dimensions. This type of description should, however, assure a high degree of compatibility with existing agricultural classification systems. This means that not only should the classes be compatible but also the method of deriving classes and their spatial and temporal dimensions (Duhamel, 1995). The spatial and temporal dimensions for cultivated areas clearly differ from (semi-)natural vegetation, as in most cases there is a constant flux in the observable cover.

Owing to this flux, the moment of observation of the land cover is very important, as the land might be ploughed, sown or harvested (with no crop actually visible), or a crop is clearly visible and different crop growth stages can be identified. These temporal dimensions influence the land cover but should not influence its description, because the area should be classified independent of the time of observation. It is for this reason that in the definition of *Cultivated Areas* provision is made for the fact that vegetative cover is not always present.

In the structural approach, physiognomy or Life Form is the principal classification criterion, followed by the vertical structure, the crop layering and horizontal structure, i.e., the Field Macropattern, of the area. This will result in detailed cover information that can be optionally combined with *Crop Type* as a specific technical attribute to establish the link with many current classification systems.

In the major land cover type of *Terrestrial Cultivated Areas and Managed Lands* (A11), *Managed Lands* form a separate category. They comprise land cover classes that are clearly vegetated and managed, though not with the intent of harvesting as is the case for *Cultivated Areas*. The structural description of their cover in this classification may appear simplistic, but a further description in land use terms would render much more information. The description in cover terms will assure a high level of mapability, which can be freely combined with user-defined land use descriptors.

A. Life Form - Managed Lands

Managed Lands form a separate category inside the *Cultivated Terrestrial Areas and Managed Lands* (A11) and consist of one single classifier: Life Form. The Managed Land

Areas are described by the Life Form composition rather than description of the individual Life Forms of the vegetation. They are defined by specifying the occurrence of trees, shrubs and/or herbaceous life forms. Three options are available: *Parklands, Parks* or *Lawns*.

Managed Lands may comprise private gardens, public green areas, sport fields, etc. They are usually found in the (peri-)urban environment. This category may be further elaborated in future to include a wider range of classifiers for more detailed descriptions.

A. Life Form - Cultivated Areas

Two main aspects of the classifier Life Form should be taken into account:

(1) the concept of Life Form in this classification; and

(2) the determination of the dominant Life Form.

Careful determination of these two main aspects is important because the classification is set up in such a way that the choice of the main Life Form has consequences for the choices available at lower levels due to certain built-in conditions.

Life Form is defined by the physiognomy of the plants. Under *Cultivated Terrestrial Areas*, Trees and Shrubs are distinguished from Herbaceous plants, subdivided into Forbs or Graminoids. Under *Cultivated Aquatic or Regularly Flooded Areas*, only Graminoid and Non-Graminoid crops are distinguished. The following rule applies: those plants that belong to the Graminae family but have a woody appearance (e.g., bamboos) are classified as Herbaceous plants. This rule differs from the rules applied in Natural and Semi-Natural Vegetation (major land cover types A12 and A24).

For determination of dominance the following rules apply:

- The main criterion is the **uppermost canopy layer**. This means that the cover goes from Trees to Shrubs to Herbaceous/Forbs/Graminoids.

- This general condition is subject to a **sub-condition of "marginality"**, i.e. the crop should cover at least 15 percent of the area and/or should return the highest economic revenue.

These two rules are the main criteria for determining the main crop. There are no restrictions to possible crop Life Form combinations (in contrast to the description of (Semi-)Natural Vegetation, as explained in the next paragraph).

The *Trees* and *Shrubs* Life Forms can have two additional modifiers: Leaf Type (*Evergreen* or *Deciduous*), in combination with Leaf Phenology (*Broadleaved* or *Needleleaved*). The introduction of this modifier for these two Life Forms assures a link with the description of the natural vegetated areas.

B. Spatial Aspect – Size and Distribution

The second classifier that can be applied is *Spatial Aspect - Size*. This classifier often implies other aspects (e.g., land tenure, mechanization, land reclamation, etc.). In many classifications one find terms like "large-scale irrigated agriculture" or similar. This classification needs to be neutral in its land cover description without including ambivalent terminology. Therefore, *Spatial Aspect* has been selected as a neutral classifier. For mapping exercises, Spatial Aspect is an important aspect at the meso- or macro-level. Furthermore, it is an easily detectable characteristic (e.g., on aerial photographs and satellite imagery), i.e., it has good "mapability."

Field Size may differ according to biophysical conditions. Therefore, the quantitative values are indicative. The classifier is applicable at the level of the individual field and three categories are distinguished:

- less than 2 ha;
- 2 to 5 ha; and
- more than 5 ha.

This classifier can be skipped because size is a very subjective element.

Spatial Distribution is the horizontal pattern of cultivated fields in a certain area. It can be easily measured, taking the distance between one field and the next. A distinction has been made into three classes:

- *Continuous* describes a continuum of more than 50 percent of cultivated fields. In this case the land cover mapping unit may be single (inside the mapping unit the fields take up more than 80 percent) or mixed (the fields occupy 51-80 percent of the mapping unit) (see also Section 2.4.2). Generally, when the fields occupy 51-80 percent of the mapping unit, the area in between the fields can be considered by the user as part of the cultivated area, or the user can decide to make a mixed mapping unit, depending which land cover features the user wants to highlight.
- The Spatial Distribution is *Scattered Clustered* or *Scattered Isolated* when, within the cultivated field area, other land cover types are present. They are defined as follows:

    1. *Percentage of fields is more than 20 percent but less than 50 percent, it is Scattered Clustered*: this means that the resulting mapping unit is a mixed land cover class of a cultivated area with another subordinate land cover class, and both components need to be defined in the legend (e.g., 40 percent of fields and 60 percent of semi-natural vegetation).

    2. *Percentage of fields is more than 10 percent but less than 20 percent it is considered Scattered Isolated*: this means that the resulting mapping unit is a mixed land cover class where the dominant class is not this one. It is the only case where a class comprising less than 20 percent is present in a mixed mapping unit (see Section 2.5).

C. Crop Combination (only for A11)

At the second level the *Crop Combination* is specified for the Cultivated Terrestrial Areas. If there is more than one crop, the crops present can be specified together with details of the possible overlap in growing period between the main and secondary crops. The order in which an additional crop is specified, follows the same condition as stated above.

- The dominance is determined by the **main criterion of the second-uppermost canopy layer**. This means that the cover goes from Trees to Shrubs to Herbaceous/Forbs/ Graminoids.

- This general condition is subject to a **sub-condition of "marginality,"** i.e. the crop should cover at least 15 percent of the area (but less than the main crop) and/or should return the second highest economic revenue.

It is important to note that the second-level classifier *Crop Combination* can also be skipped by the user because of the apparent difficulty in determining the classifiers correctly. This skip function will then permit the user to continue the description of the main crop at the third level.

C. Water Seasonality (only for A23)

The second level classifier *Water Seasonality* of Aquatic or Regularly Flooded Cultivated Areas describes the duration of water on or near the surface during the main crop cultivation period. If any additional crops are cultivated after, or in overlap with, the main crop the period of water at or near the surface for these crops should be neglected.

D. Cover-Related Cultural Practices – Water Supply and Cultivation Time Factor (A11)

At the third level of classification the classifier *Cover-Related Cultural Practices – Water Supply* is determined. The options *Rainfed Agriculture*, *Post Flooding* and *Irrigated Agriculture* for Cultivated Terrestrial Areas have implications for the options available under *Cultivation Time Factor*. *Post Flooding* cultural practices are not possible in a *Permanent Cultivation* system. It is also obvious that the dominant crop determined will have implications for other classifiers (e.g., a Tree Crop will result in a Permanent Cultivation system).

A Permanent Cultivation system in combination with either a Trees or Shrubs Life Form designates what is commonly known as plantations and orchards (e.g., a forest plantation or a coffee plantation). However, these names do not occur *per se* in this classification system. In combination with Crop Type, a link to current systems can be made and to commonly used names such as "plantation" (e.g., the combination of *Shrub Crop* and *Crop Type: Tea* covers "Tea Plantation," while *Tree Crop* and *Crop Type:* Hevea *spp*. refers to "Rubber Plantation").

D. Cover-Related Cultural Practices – Fallow Period (only for A23)

Cover-Related Cultural Practices – Fallow Period is the third level classifier for Aquatic or Regularly Flooded Cultivated Areas. It has three subdivisions: *Permanent*, *Relay Intercropping*, and *Sequential*. They are, however, defined differently from Cultivated Terrestrial Areas because they refer to the practices that occur **after** harvest of the main aquatic crop (see also the Glossary). These practices may not relate to the same Aquatic or Regularly Flooded environment of the main crop.

2.3.4. Classification Concepts for *Primarily Non-Vegetated Areas*

Areas primarily characterized by a cover other than vegetation fall into two categories: those with a non-vegetal cover and those with no cover at all. The latter is a category that describes the land surface rather than any cover of the land but which has been included here, as explained earlier (see Section 1.1).

The approach adopted for describing *Primarily Non-Vegetated Areas* is, as for Vegetated Classes, a "structural-physiognomic" approach, that is the physiognomy, the cover (i.e., density) and structure are used as parameters. The classifiers *Surface Aspect* (*Artificial Surfaces* and *Bare Areas*) and *Physical Status* (*Artificial and Natural Waterbodies*, *Snow and Ice*) can be regarded as descriptors of the physiognomy of the materials, like Life Form for vegetation. The further classifiers and modifiers of Bare Areas and Artificial Surfaces contain elements of *Cover*, as for Terrestrial Vegetation, whereas the *Water Persistence* classifier is similar to *Water Seasonality* in Aquatic Vegetation.

2.3.4.1 Artificial Surfaces and Associated Areas (B15)

Areas with an artificial cover resulting from human activities are described in most classification systems in terms of use, whereas the description of cover is equally important. An example is urban areas where the surface generally consists of impervious materials. This type of impervious surface greatly influences run-off and the peak flow characteristics of water. Another example is tarmac roads in hilly terrain, where road constructors need to carefully plan for the discharge of excess water that, in poor designs, may lead to disastrous forms of erosion.

The Associated Areas are mainly domains where the original surface is removed, such as extraction sites, or where materials have been deposited on top of the original surface, such as waste dumps and other type of deposits.

The characteristics of the cover of the surface are crucial in the land cover description and therefore embody the main classification concept. This major land cover type is classified depending upon the Surface Aspect. A category for the Built-Up Object can be specified using the scroll list (e.g., cities and towns, roads, open mines, official waste dump sites, etc.).

A. Surface Aspect

The *Surface Aspect* distinguishes two main classes, with one class having two levels with an increase in detail. A much more detailed class description can be made using the modifier options. These modifiers are explained in terms of cover rather than land use terminology.

The *Artificial Surface* areas can be further defined according to the shape and density of the artefacts.

2.3.4.2 Bare Areas (B16)

Areas which are primarily bare are usually described by geologists, soil scientists or geomorphologists (using technical terms like granite rock, rendzhina, sand dunes, inselberg, tor, etc.). This type of description is highly technical, and may be difficult to understand for users with a different background. An approach is therefore needed which describes the type of material on the surface, with additional options to go into more detail, in combination with elements describing either some specific properties (physical or chemical) of the surface material, or describing some specific forms. Specific forms implies that the

surface may consist of shapes that form a pattern at the macro-level. The focus of the cover description is on the surface and not on the subsoil.

The major land cover type *Bare Areas* is, therefore, described mainly by the appearance of the surface. The concept adopted describes the aspects of the cover: whether it is consolidated or not, and of what kind of material it comprises (e.g., rock, sand, etc.), and which may be combined with Macropattern. The more discipline-related descriptors for geology, landform and soil are available as attributes and can be used to link the land cover description to the technical disciplines.

A. Surface Aspect

The *Surface Aspect* describes the surface of the Bare Area at two levels, with an increase in detail. A further specification can be made by using one of the modifiers. These modifiers specify some physical or chemical properties.

B. Macropattern

The *Macropattern* describes the pattern of the surface. This classifier is linked to the *Surface Aspect* because a *Macropattern* can only be of the same material as the surface described. Hence the choice made under *Surface Aspect* may disable certain choices in this classifier. Two types are distinguished, namely *Bare Soil* and *Loose and/or Shifting Sands*.

2.3.4.5 Artificial and Natural Waterbodies, Snow and Ice (B27 and B28)

The two major land cover types describing water surfaces or other physical appearances of water, *Artificial Waterbodies, Snow and Ice* (B27) and *Natural Waterbodies, Snow and Ice* (B28) are described by taking into account their temporal aspect. Water, snow and ice may not be present all year round and therefore it is also important to know what the cover is when they are absent. This temporal aspect should not influence the classification results because classification by default is independent of temporal change.

In most existing classification systems these land cover types are only briefly described in terms of cover, with no additional information. The concept adopted by this classification puts more emphasis on the temporal aspect.

The major difference between these two major classes is that *Artificial Waterbodies, Snow and Ice* are surfaces in places where, under natural circumstances, no water, snow or ice surface would exist. Therefore these surfaces are the result of an artefact, such as the construction of a dam, the making of artificial ice or snow, etc.

A. Physical Status

The *Physical Status* describes in which form water is found. Three options are available: Water, Snow or Ice. Depending on the choice made here, other classifiers at lower levels may be disabled. For water and ice a further specification can be made into Flowing or Standing Water and Moving or Stationary Ice.

B. Persistence

Persistence, i.e., the duration that Water, Snow or Ice covers the surface, is described. If Water, Snow or Ice is present for nine months or less per year, the surface then exposed can be further specified.

C. Depth

The *Depth* can be described because this is directly related to cover aspects. The proposed classifier has not been given a lot of detail because the most important feature to be determined is whether it is deep or not, i.e., whether it is shallower or deeper than 2 m. This limit has an ecological meaning as it is the maximum rooting depth for the great majority of aquatic plants (Cowardin *et al*., 1979).

D. Sediment Load

The suspended *Sediment Load* in the water influences the cover and implies other environmental aspects, such as upstream erosion and downstream sedimentation. It also influences the aquatic fauna and flora. It is a relatively easily observed characteristic of the water, but difficult to measure as it fluctuates. Therefore the subdivision has not been given great detail.

2.3.5 Environmental and Specific Technical Attributes

The pure land cover classifiers can be combined with so-called attributes for further definition (see also Section 2.3.2.) of the land cover class. These attributes are intended to be used as a further characterization of the land cover itself rather than to add a new data layer. Application of the attributes in the full legend, when all classes would have the same set of attributes, they could be used as a separate layer in the database. Two types of attributes, which form distinct levels in the classification, are distinguished:

Environmental Attributes: attributes that are not inherent features of land cover but may influence the land cover.

Specific Technical Attributes: attributes referring to the technical discipline of the major land cover type.

2.3.5.1 Environmental Attributes

L. Landform

Land forms are described first and foremost by their morphology, and not by their genetic origin or the processes responsible for their shape. The dominant slope is the most important differentiating criterion, followed by relief intensity.

This attribute can be applied to all classes except Artificial Surfaces and Artificial and Natural Waterbodies, Snow and Ice. The attribute consists of two different levels, that is major land form and slope class according to the Soils and Terrain (SOTER) methodology (UNEP/ISSS/ISRIC/FAO, 1995).

M. Lithology

The lithology can be described based on the geological parent material and the age of it. The options provided have been provided by S.B. Kroonenberg (1998). Three major groupings are distinguished and further subdivided (see Glossary).

N. Soils

For the *Primarily Vegetated Areas*, the user can describe first the soil's Surface Aspect, followed by a detailed description of the soil profile according to the Revised Soil Legend (FAO, 1988). For *Bare Areas* (B16) only the soil profile description is applicable because the soil surface aspect is a classifier of this major land cover type.

O. Climate

The concept adopted to add climatic parameters to the land cover classes is from De Pauw *et al.* (1995). The revised Length of Growing Period (LGP) approach gives recognition to the relevant climatic constraints in any major region of the world. The combination of Thermal Classes and Moisture Classes gives the climate. No conditions have been pre-set.

P. Altitude

This attribute can be used in all major land cover types. The classes of this attribute are a proposal and can be further subdivided by using the possibility available in the Legend Module to create a user-defined attribute (see Section 5.2.5).

Q. Erosion

In the description of *Erosion* in the land cover, emphasis is given to accelerated or human-induced erosion. Human-induced erosion is often the result of irrational use and poor management, such as incorrect agricultural practices, overgrazing or overexploitation of the (semi-)natural vegetation. These practices result in a cover type with specific features. Most of the erosion can be classified as either Water or Wind erosion and deposition, with the Mass Movements as a third major category. Further subdivision can be made by using the User-defined Attribute option in the Legend Module.

This attribute is applicable in all *Primarily Vegetated Areas and Bare Areas* (B16).

R. Water Quality (only for A24)

This attribute is only applicable in *(Semi-)Natural Aquatic or Regularly Flooded Terrestrial Areas* (A24). It can be used to specify the salinity of the water (measured in ppm of TDS) according to Cowardin *et al.* (1979).

U. Vegetation (only for B16, B27 and B28)

This attribute is applicable for *Bare Areas* and *Artificial and Natural Waterbodies, Snow and Ice* (e.g., sandy riverbed with scattered vegetation) to indicate that less than 4 percent of vegetation is present. In the case of the presence of Lichens and/or Mosses, they should be less than 20 percent (see Glossary).

W. Cover/Crop Density (only for A11 and A23)

This attribute is only applicable for the *Cultivated Areas*, both *Terrestrial* and *Aquatic or Regularly Flooded*. This attribute gives information on the density of the permanent crops, (e.g., Trees and Shrubs), or the cover of the temporary life forms (e.g., Herbaceous, Forbs and Graminoids). This information is an indicator of the success of crop establishment and hence its possible yield.

The density has not been used as a land cover classifier, as for (semi-)natural vegetated areas, because it normally would not add any useful information to the land cover class. The density is related to the planting distance of the crop, which differs according to crop (e.g., olive trees versus maize). However, it is a useful attribute when describing a cultivated area which does not have the expected density of the crop (e.g., in marginal areas).

2.3.5.2 Specific Technical Attributes

These attributes are related to the technical discipline associated with the major land cover type: thus, for (Semi-)Natural Vegetated, areas the Floristic Aspect can be described; for Bare Areas, the Soil Type (as discussed under *N. Soils*); for Cultivated Areas, the Crop Types; and for Artificial and Natural Waterbodies, Snow and Ice, the Salinity.

S. Crop Type (only for A11 and A23)

The *Crop Type* can be specified according to the major groupings used for the FAO Production Yearbooks. If a *Crop Type* is not present, it can be defined and added under the header *Other* in the boxes which open upon clicking. Furthermore, the name of the crop has to be linked to the dominant, second or third crop choices, if not the entry is not saved. Thus, a maximum of three names can be specified.

T. Floristic Aspect (only for A12 and A24)

This attribute has two major divisions: if the name is derived from a single plant species or a group of plants. In the first option, a further subdivision is possible into *Dominant Species* (Height, Cover or combination of both) and *Most Frequent Species*. The second option is subdivided into: *Plant Groups* (e.g., Braun-Blanquet) and *Plant Groups Derived Without Statistical Methods* (e.g., same ecological significance, same geographic distribution, same dynamic significance, etc.). The specific name of the *Floristic Aspect* can be added with the User-Defined Attribute option in the Legend Module.

V. Salinity (only for B27 and B28)

The *Salinity* of the water can be specified for *Artificial and Natural Waterbodies.* Three main classes are distinguished, based upon Cowardin *et al.* (1979).

2.4 THE ADVANTAGES OF THE METHOD ADOPTED

2.4.1 Advantages from the conceptual point of view

It is a real *a priori* classification system in the sense that, for the classifiers considered, it covers all their possible combinations. Some particular combinations are excluded, due to conditions that are elements of the classification system. In this case the type of combinations and the conditions, i.e., the reasons, for this "exclusion" are clearly listed and explained.

A given land cover class is clearly and systematically defined making a clear and unambiguous differentiation by use of the classifiers as follows:

- pure land cover classifiers (each one ordered from general to more specific level);
- environmental attributes (e.g., Climate, Landform, Geology, etc.); and
- specific technical attributes (e.g., Floristic Aspect for (Semi-)Natural Vegetation).

This system avoids unclear definitions (e.g., "tropical rain forest" where a climatic attribute is used for a floristic description).

The classification is truly hierarchical. The class' hierarchical arrangement is a basic component of the mechanism of the class formation. The difference between a land cover class (at a more general level) and a further subdivision of it is given through the addition of new classifiers (or a more detailed level of the one forming the previous class). The more classifiers used, the greater the detail of the land cover class defined.

The classes derived from the proposed classification system are all unique and unambiguous, due to the internal consistency and systematic description of the class as a basis for objective and repeatable classification. Correlation studies between classifications show that in many cases definitions of the class names are often either unclear or unsystematic, or both, due to the fact that in traditional classification and legends the "meaning" of a class is derived only from its general description. Such a descriptive text is very often unsystematic, and as a result in many cases there are insufficient details to define strict boundary conditions. The classes are therefore open to misinterpretation and lack internal consistency. With the present classification the user's primary descriptive tool is the Boolean Formula of all classifiers used to build the class; this cannot be anything other than a systematic description of the class. In addition to this, the traditional class description is used. A strict class boundary definition and internal class consistency are inherent to the method.

LCCS is designed to map at a variety of scales, from small to large (see Section 3).

For two main reasons, the classification can be used as reference classification:

- the classification contains a large number of classes (the classes of the existing classifications and legends can always be accommodated); and

- emphasis is on a set of classifiers rather than just a name, which allows easy correlation even when a range of values, such as the percent of cover of a given life form, does not fit with the proposed value; the dissimilarity is clear and remains limited to only a portion of the elements forming the class. This event however should be extremely rare due to the different levels, from more general to more specific, forming a single type of classifier.

2.4.2 Advantages from the practical point of view

The specific design of the classification allows easy incorporation and integration into GIS and databases. The mechanisms of how the classes are built up (see Section 2) facilitate overlay procedures.

It will produce a real multi-user database. Despite the high demand for natural resources information, many databases are not developed to meet multi-user requirements. This is shown by the fact that very often the number of real users is often a small portion of the potential ones. An important cause is the inherent rigidity of the natural resources information (i.e., land cover) of the databases. Two cases are typical:

- the original project is very specialized (e.g., vegetation ecology), and hence the class name and description of the resulting legend are difficult to understand by other users (such as rural planners, statisticians, etc.); or

- the original project is not specialized, and so the classes or the class descriptions are too generic to be used by specialized disciplines.

The ways in which current classifications determine the classes (names and generally a broad description) do not allow a great deal of flexibility of use by the final user. The present classification system assumes two types of final users:

- the one that uses the classification to built up the database (the user basically doing the interpretation activity); and

- the one that is the final user of the database created.

The system obliges the first user (the database builder) to follow specific rules in the combination of classifiers (to assure standardization and comparability of the data set) but allows the database user (see Section 3) to define freely the set of classifiers with which they wish to re-aggregate the original polygons of the database. Because the class definition is linked with the classifiers' Boolean Formula, this is a straightforward process. Of course, the number of potential recombination of classifiers is extremely large, and some combinations may be illogical, but this respects the concept of multiple users, each with their very specific needs.

For interpretation purposes, the advantages are:

1. It is highly flexible, responding not only to the information available or gathered in a given area, but also to the time and budgetary constraints of a project. This means that within one land cover map, mapping units will contain the maximum available information, but that the quantity of information may differ between the mapping units. This will not affect the homogeneity of the resulting map. It will be possible, for instance, to have within the same map, in a certain geographical area polygons of a class formed with a certain number of classifiers (a high number as here more ancillary information is available), while, in another part, polygons where the same type of class will have fewer classifiers. It will always be possible to compare the two classes.

2. It rationalizes the field data collection. Because the classes are defined by a combination of classifiers, field surveyors should detect the single classifiers and not deal with the final class name. This means that the field survey can be done independent of, or parallel to, the interpretation process.

3. It facilitates standardization of the interpretation process, contributing to its homogeneity. Despite the huge number of classes the interpreter can generate to fit the land cover variations, one is dealing only with a limited number of classifiers. So one does not need to scroll inside a big, obscure list of class names but must simply aggregate a limited number of well-defined classifiers. This will also reduce heterogeneity between interpreters and between interpretations over time.

4. It allows the building up of a new procedure of accuracy analysis of the result. Until now, accuracy analysis was done for single classes; henceforth it will be possible to assess the accuracy not only for the entire class but also for each of the classifiers forming the specific class. This will give a high flexibility to finalization of the classes. If, for instance, a class formed by five classifiers shows an accuracy of 60 percent, which is too low according to the established standard, then by looking at the individual classifiers forming this class the user can analyse the contribution of each individual classifier to the overall class accuracy. If, in the example, the first four classifiers have an accuracy of 90 percent while the fifth classifier only 60 percent, the user may decide to eliminate this last and less accurate classifier in order to have a final class with less detail but with a higher accuracy.

2.5 FROM CLASSIFICATION TO LEGEND

Classification is an abstract representation of the situation in the field using a particular set of diagnostic criteria, whereas a legend is the application of the classification's abstract design in a particular area using a defined mapping scale and a particular data set. This transition implies establishment of specific conditions not present in the classification concept (e.g., Minimum Mapable Area and Mixed Mapping Units). Because one of the ultimate goals of this classification is to provide a useful tool for mapping exercises, these conditions will be discussed here even if they are not strictly appropriate to the main subject of this chapter.

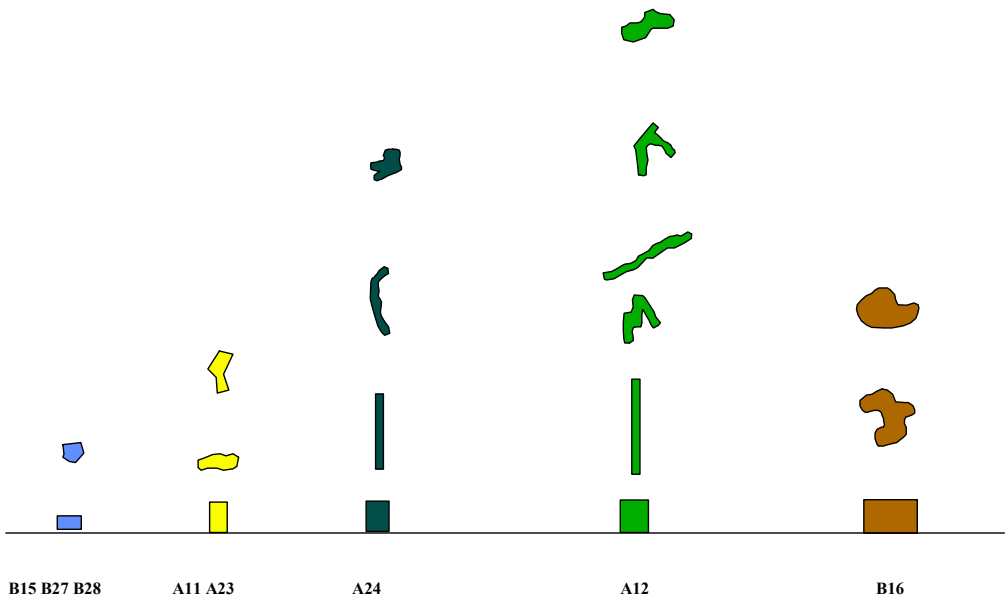
2.5.1 The *Minimal Mapable Area* concept

The *Minimal Mapping Area* is a concept applied by cartographers when addressing the smallest area that can be shown on a map. This concept is therefore scale-dependent and not related to classification. However, the issue is addressed here as it usually poses problems.

The concept of one single mapable area is generally applied. Historically, the cartographer determined one particular minimum size of area to be represented on the map. This was applied to all classes contained in the legend. The disadvantage of this method is that classes with a difference in importance would follow the same rules. It would have been more logical to define a set of different sizes for the various features with differing importance (Di Gregorio, 1991).

The flexibility of this current classification allows the introduction of the concept of a variable minimal mapable area. Thus, the user can relate the size of the minimal mapable area to the eight major land cover types from which the classes are derived (Figure 10).

FIGURE 10.
Example from the East Africa Project, with variable minimal mapable areas (not at original scale).



2.5.2 The Occurrence of Mixed Mapping Units

In the classification system, all classes are unique and no Mixed Mapping Units are considered. Mixed Mapping Units are cartography related. However, the user can go from a more general to a more detailed level of definition of a class. If for instance the classifier *Woody* is used, this implies that an intricate mixture of trees and shrubs is present in which neither is clearly dominant. This results in a mixture of two life forms but not in a mixed land cover class. A Mixed Mapping Unit in the legend is always characterized by two or more (to a maximum of three) separate single land cover classes as defined in the classification system. The conditions governing the utilization of mixed mapping units are that within the minimum mapable area, two or more land cover classes are present, which can be:

(1) in a spatially separate entity (e.g., patches of agriculture fields inside a forest); or

(2) in an intricate mixture (e.g., rainfed cultivated fields with Baobab woodland).

The latter is applicable only if a more general definition of the class (as explained above) is not appropriate.

In the case of spatially separate entities of two or more classes, the general criteria proposed is that the cover of each one of the class considered must be more than 20 percent (and consequently less than 80 percent) of the mapping unit. The limit of 20 percent is thus the threshold of "visibility" of a class in a Mixed Unit. The only exception to this rule is in the major land cover type of *Cultivated Areas,* where the use of the option *Scattered Isolated* of the classifier *Spatial Distribution* goes from 10 to 20 percent (see Section 2.4.2).

The sequence of the class names in a mixed mapping unit represents the dominance (e.g., for *Forest/Cultivated Areas,* Forest is more than 50 percent and less than 80 percent, whereas Cultivated Areas is less than 50 percent but more than 20 percent). A Mixed Mapping Unit can contain a maximum of three classes.

In the particular case of classes belonging to the major land cover categories *Cultivated and Managed Terrestrial Area(s)* (A11) or *Cultivated Aquatic or Regularly Flooded Area(s)* (A23), the user has an additional means to create a Mixed Mapping Unit. The classification system offers the possibility to create a so-called "Temporal Mixed Unit". Such a unit is used to describe the situation were in different years, different types of cultivation are executed in the same field (i.e. the mapping unit). This is the case when the user has, for example, a situation with cultivated fields of paddy rice in one year (e.g. when there is sufficient rainfall) followed by a terrestrial crop in the subsequent year(s) (e.g. when rainfall is poor). This particular type of Temporal Mixed Unit shows often a cyclic, almost customary, alternation of different crops in subsequent years (e.g. generally an Aquatic crop followed by Terrestrial crops, or an Irrigated crop followed by Rainfed crops, etc.). It is important to note that **the alternation of crops should be considered only when this occurs on an annual basis**. The combination of different crops in the same growing period is an option already considered in LCCS' class creation (see the classifiers related to Crop Combination in A11). However, because of the specific nature of this type of Mixed Unit, that occurs only where crops are growing, the **classes composing such a mixed unit can only be those of Cultivated Area(s)**.

- PART B -

Land Cover Classification System: User Manual

For software version 1.0

3. INSTALLATION

A user-friendly interface has been built between the set of databases holding the numerous potential land cover classes formed by selection of the classifiers and attributes available. The branching options in the classification system are many and the software application should make any of these classes easily retrievable. ACCESS 7.0 has been used as the development platform.

This section of the User Manual will cover:

- hardware and software requirements;
- installation procedure; and
- directory structure.

Before trying to install the Land Cover Classification System ensure the PC meets the requirements specified below.

Please note that LCCS comes as a run-time software application, therefore, it is not necessary to have ACCESS7.0 installed on your computer.

System Requirements

Hardware:

- Pentium processor
- 8 MB RAM (16 MB or more recommended)
- Hard disk with at least 25 MB of free space
- The screen size can be variable

Operating System:

- Windows 95 or Windows NT

Installation Procedure

LCCS comes as a Run-time version. The users have to follow the regular installation sequence for Windows-based programs.

For Windows 95 and NT users, the procedure is as follow:

(1) Insert the CD-ROM in your CD-ROM drive (in most cases D:)

(1) Click on Start

(2) RUN

(3) type *D:setup*

After having completed this step, a guided set-up procedure is activated. It is highly recommended that its proposals be accepted regarding the installation directory and naming of new program groups.

At a certain point in the set-up procedure a MSDOS window is opened where the user has to touch a button to proceed. After completion this window can be closed a window with the message "*Land Cover Classification System Setup was completed successfully*" will be displayed. Click the *OK* button to exit the set-up.

At the end of the set up, a new sub-directory C:\LCCS is created and a new Land Cover Classification System icon is added to the WINDOWS Program Manager.

Directory Structure

The installation looks for the following directory structure and - if necessary - creates it:

- C:\LCCS contains the database software and the databases as such.
- C:\LCCS\DOCS contains the WinWord documentation files for LCCS.
- C:\LCCS\IMAGE contains the example image files delivered with LCCS.

4. OPERATION

Though no previous knowledge of Microsoft WINDOWS is required to operate LCCS, there are some Selection Techniques and Screen Objects the user should become familiar with in order to be able to use the LCCS Action Panel without problems.

Selection Techniques

- *Mouse click:* moving the arrow shaped mouse cursor to an object (such as a button or a symbol) and pressing the mouse's left button once.

- *Double click:* as above, but pressing the left mouse button rapidly twice.

Screen Objects

Typical objects in LCCS, through which the user communicates with the program by making a selection or triggering an action, are:

- *Buttons*: clicking when the mouse arrow is over a button object triggers the action usually displayed as the button's label (like making a menu choice or quitting a program).

  Buttons can take 3 different states:

  Enabled but not activated: button takes a risen appearance.

  Enabled and activated: button takes a sunken appearance.

  Disabled: a button that is disabled cannot be activated; its label shows as lighter grey.

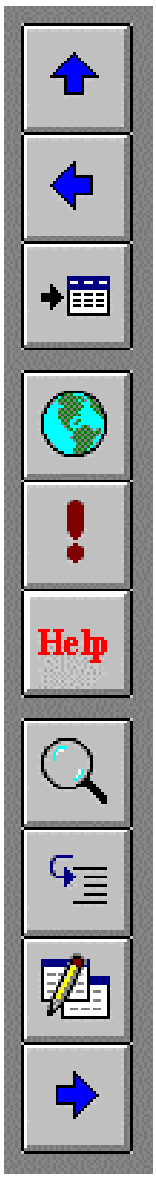
- *Combo Boxes*: these boxes let the user select from a list of items. By typing the first few characters of a possible choice in the box a matching entry will be displayed and can be selected by pressing <Enter> or by double-clicking the requisite list item. A list of entries unfolds upon clicking the down-arrow at its right hand side. An entry can be selected by double-clicking on it. Should the list be longer than the size of the box, vertical scrollbars are displayed at the right hand side of the box, inviting the user to click on the up or down arrows to see further entries in the list box.

- *LCCS Sub-menus:* like the Main Menu screen, the LCCS sub-menus let the user branch to further options by clicking on one of the menu buttons.

- The *F1 Key/Help*: pressing the F1 key in any of the forms/screens of LCCS brings up a context-sensitive Help screen. The effect of pressing the F1 key is the same as clicking on the 'Help' button.

The Classification Module Actions Panel appears in the majority of forms/screens of this module. This panel contains 10 buttons that trigger different actions (Figure 11).

FIGURE 11.
The Actions Panel in the Classification Module.



End Classification

Previous Form/Screen

Legend Menu

Image Database

Show Classifier Codes

Context Sensitive Help

Show Class

Write Class to Legend

Attributes Menu

Next Form/Screen

The buttons of the Action Panel trigger the following events:

- *End Classification*: This button opens a box containing the question "Do you really want to quit Classification?" with the options Yes or No.

- *Previous Form/Screen*: This button brings the user back to the previous form/screen, with all previously selected buttons visible.

- *Legend Menu:* This button brings the user to the Legend Module menu.

- *Image Database:* This button activates stand-alone commercial public domain software for image (e.g. satellite imagery) display.

- *Show Classifier Codes*: This button opens a window with the relevant classifier options and their corresponding codes. The Close button can be used to close this window.

- *Context-sensitive Help*: This button opens the Help facility of the current major land cover type the user is in, and which contains all definitions and guidelines for the correct use of the classifiers, modifiers and attributes.

- *Show Class*: This button opens a new window in which the classifier, modifier and attributes codes used can be viewed, as well as the name of the land cover class. The button in the lower right-hand corner can be used to close this window.

- *Write Class to Legend*: This button opens a window in which the user has to select one of its options before the class can be successfully written to the Legend Module (for further explanation see Section 5.2).

- *Next Form/Screen*: This button brings the user to the next level of the classification and is only enabled when all available classifiers in the form have been determined. This button is not available for environmental and specific discipline related attributes.

The buttons are in the enabled position when the action they trigger is valid. *The Show Class* button in the enabled position indicates that a land cover class has been formed, that is the minimum set of classifiers to define a land cover class has been determined.

In the Legend Module the screen objects consist of buttons that may or may not be followed by a combo box or sub-menu with several options, as described earlier.

For the main Legend menu options *Display*, *Standard Description* and *Classifiers Used*, a report will be shown which can be printed. The same applies for *Similarity Assessment* in the Translator Module.

In the Translator Module the selection technique consists of clicking on button objects or highlighting a selected item by clicking once on it (especially in list boxes).

5. THE PROGRAM MODULES

Each of the four modules will be discussed in detail regarding its purpose, the options available and the links with other modules of the software.

5.1 CLASSIFICATION

5.1.1 Purpose

The purpose of this module is to define a land cover class according to two main phases:

- An initial Dichotomous Phase, where the user derives the main land cover type. For this phase at each level a choice is made between two alternatives, hence the term *dichotomous*. After having determined the main land cover type, the user can proceed to the next Phase, but the user can also define a generic class using only this initial phase.

- A subsequent Modular-Hierarchical Phase, where a land cover class is defined by determining one classifier at a time. The classifiers available are tied to the main land cover type. In this Phase, the selection of one classifier at a high level may have consequences for the options available at lower levels. The system is constructed in such a way that choices no longer valid in connection with a chosen classifier at a higher level become inactive.

At any level within these Phases the user can ask for the land cover class and store its Boolean formula, numerical code and class name in the module called "Legend."

5.1.2 Dichotomous Phase

In the Dichotomous Phase the user can select the major land cover category to which the land cover belongs. There are two ways to proceed through the options, to either:

- start at the top of the key and determine at each level which option is valid by clicking the appropriate button; or

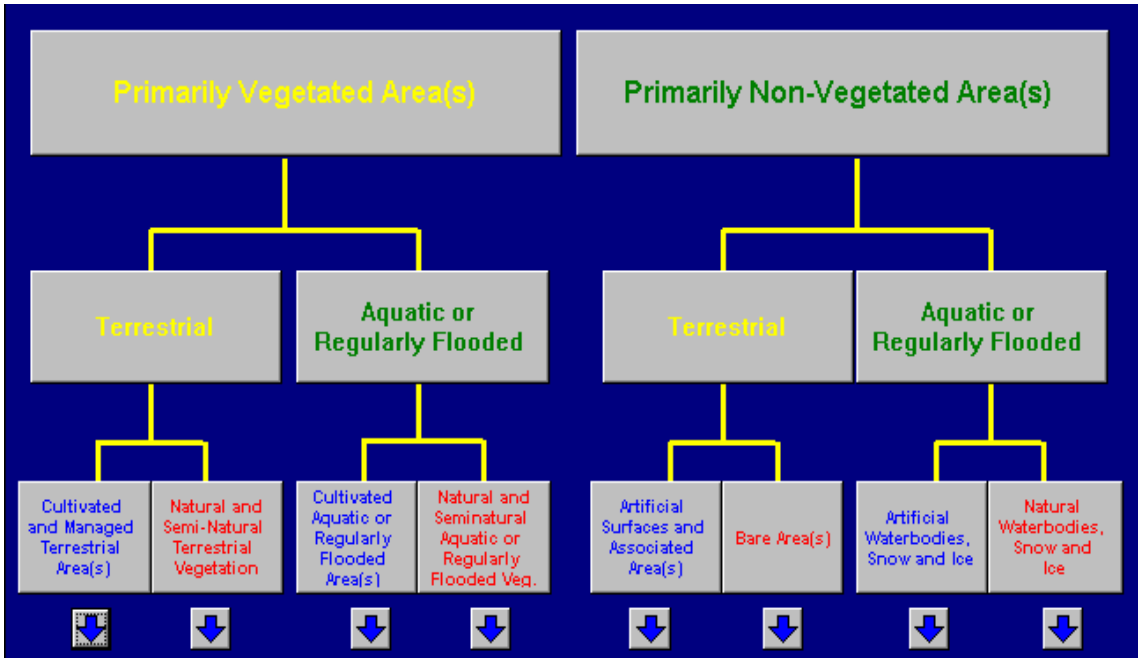
- identify immediately to which major land cover type the class will belong and by clicking directly on the button with the arrow immediately below the button with the major land cover type name.

Having determined the major land cover type (Figure 12), the Dichotomous Phase is completed and the user automatically enters the next phase. A pop-up screen will inform the user of the change of Phase.

If the level of information needed or available to determine a land cover class is very limited, the user can select the appropriate choice(s) in this phase and a land cover class will be defined. This class will consist of a Boolean formula, a standard name and numerical code. This class can be stored in the Legend Module (see Section 5.2). Classes thus defined are broad categories because of the limited number of classifiers used. For more detailed definition of classes the user should apply the classifiers of the Modular-Hierarchical Phase.

FIGURE 12.

The Dichotomous Phase with the classifier options *Primarily Vegetated - Terrestrial - Natural and Semi-Natural Vegetation* selected.



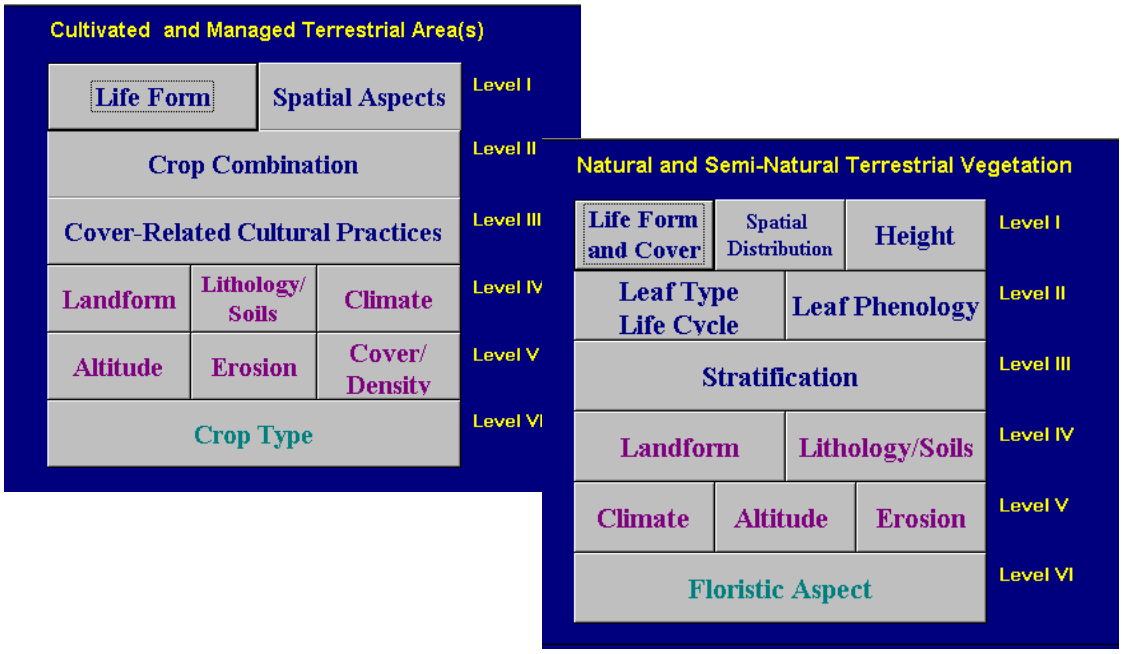
5.1.3 Modular-Hierarchical Phase

The Modular-Hierarchical Phase is a phase where the set of available classifiers is tailored to the major land cover type. This means that the type, amount and hierarchical arrangement of classifiers will differ from one major land cover type to an other.

In each module, however, three groups of classifiers and attributes are available and they are always presented in the same hierarchical order. Each type of classifier and attribute is also presented in a different colour on the video screen (Figure 13). A distinction is made between:

- pure land cover classifiers at the top levels of the module;
- environmental attributes at the intermediate levels; and
- specific technical or discipline-related attribute at the bottom level.

FIGURE 13.
Example of the classifiers and attributes of two major land cover types: *Cultivated and Managed Terrestrial Areas* (A11) and *Natural and Semi-Natural Terrestrial Vegetation* (A12).



Pure Land Cover Classifiers

The difference between these classifiers and the attributes is that the land cover classifiers are strictly hierarchically ordered. One cannot skip a classifier and go on to the next one unless this possibility is provided for by the program, as occurs with "Semi-Natural and Natural Vegetation" and "Cultivated Terrestrial Areas and Managed Lands". The user must proceed step-by-step in order to develop the structural-physiognomic concept (see Sections 2.3.4.1 and 2.3.4.2).

The classifiers are also ordered according to their mapability. The classifiers at a high level have a higher mapping accuracy than classifiers from lower levels, which means that they will contribute more to establishing clear and precise boundaries between different land cover classes than will lower-level classifiers. If a classifier cannot be determined, the user can stop.

Definition of the land cover class results in:

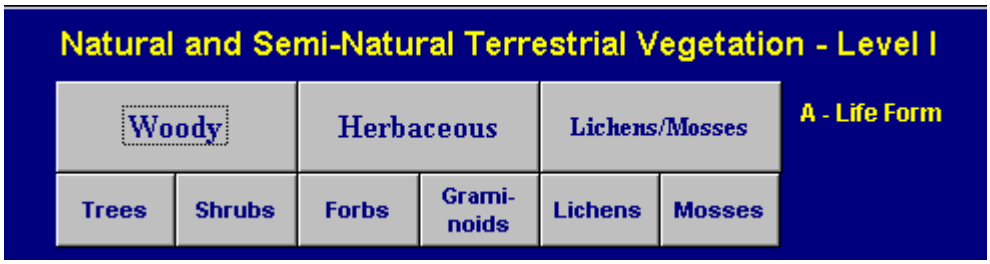
- a unique Boolean formula (a coded string of the classifiers used);
- a standard name (nomenclature); and
- a unique numerical code that may be useful in GIS applications.

Both the numerical code and nomenclature name can be used to automatically generate a Legend (see Section 5.2).

The user will start to identify any land cover class using the pure land cover classifiers. A minimum number of these classifiers need to be determined before the user is allowed to combine these classifiers with any of the attributes. If the minimum requirement for classifiers has been satisfied, the button for proceeding to the environmental attributes will be enabled, as well as the buttons to show the class and save it to the Legend.

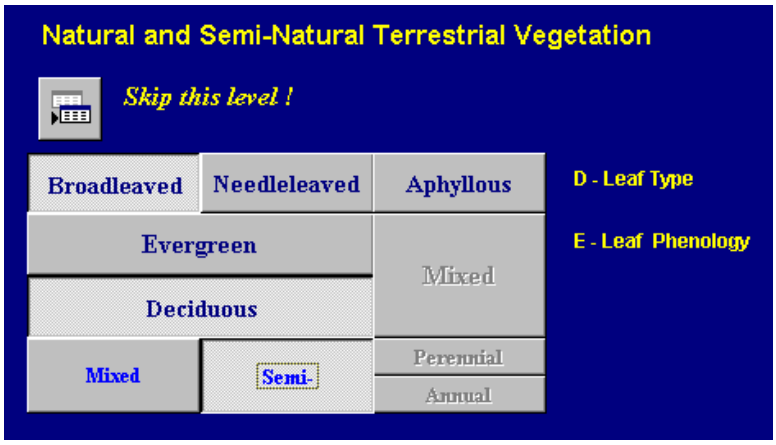
The pure land cover classifiers are always presented in blocks in which the choices are mutually exclusive, i.e., the user can select only one option. Even where there are two different levels, a more general level and a more specific level, presented in two rows (e.g., in Life Form "Woody" above "Trees" and "Shrubs" in Figure 14) only one option can be selected. If the user clicks on the button "Woody" followed by clicking on "Trees", the button "Woody" will return to its original, inactive, position.

FIGURE 14.
Example of classifier options at different levels of detail (major land cover type A12 - classifier *Life Form* with a first general level and a second more detailed level).



There are also options that further modify a classifier option (Figure 15). These are called Modifiers and they immediately follow a classifier option (e.g., in Leaf Phenology for Forbs and Graminoids "Mixed" above "Perennial" and "Annual", or in Height for all Life Forms). Modifiers belonging to one classifier option are mutually exclusive. Only after selection of the classifier can a modifier be added. If the user clicks the button of a modifier without having clicked on the appropriate classifier first, a message will pop up to inform the user that the classifier should be selected first.

FIGURE 15.
Example of modifier that further defines a classifier option (major land cover class A12 - classifier *Leaf Phenology* with modifier options *Mixed* and *Semi-Deciduous*).

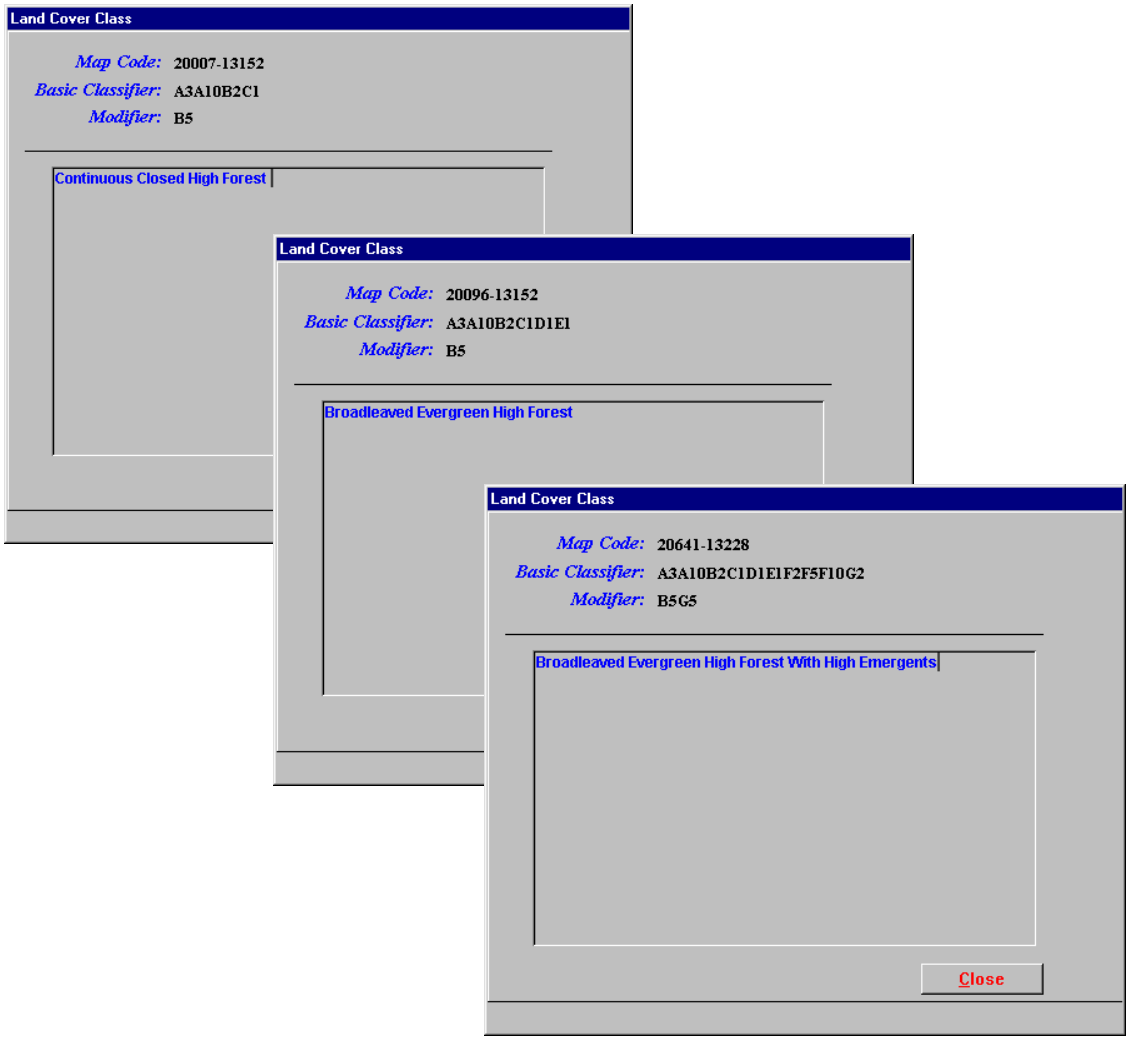


The use of these modifiers will generate (examples are shown in Figure 16):

- a separate Boolean Code (e.g., "Basic Classifier: A3A10B2C1" and "**Modifier: B5**")
- a distinct numerical code which follows the classifier code and is separated from it by a hyphen (e.g., 20007-**13152**); and
- a change to the standard name (e.g., Continuous Closed **High** Forest).

The more levels with their classifiers that are used, the more specific becomes the land cover class defined. Choices made at a high level may have implications for the availability of a certain classifier at a lower level. If certain options are no longer valid the buttons are disabled. In this way the user is guided through the program and invalid choices prevented.

FIGURE 16.
Examples of *Show Class* windows with a land cover class defined in the *Natural and Semi-Natural Terrestrial Vegetation* major land cover type.



Environmental Attributes

The environmental attributes are not hierarchically ordered and the user is free to add appropriate choices in any order. Use of these attributes further defines the environmental settings in which a land cover unit is found (Figure 17). The options within one environmental attribute are mutually exclusive. Use of attributes will result in:

- a separate string of codes in the Boolean formula (e.g., Basic Classifier: A3A10B2C1-**L2L7**, Modifier: B5);
- no alteration of the numerical code (e.g., 20007-13152 remains unchanged); and

- no change in the standard name, as these choices follow the standard name and each choice refers back to the attribute itself (e.g., Class Name: Continuous Closed High Forest; **Major Landform: Sloping Land; Slopeclass: Rolling**).

FIGURE 17.
Example of *Show Class* window with a land cover class with additional environmental attributes: Landform and Climate.

Specific Technical Attribute

Use of the specific technical attribute will further define the land cover class using the related discipline (e.g., for vegetation, the method of how species were recorded can be specified; for cultivated areas, the crop type can be specified)(Figure 18). Again choices are mutually exclusive. Use of a specific technical attribute will result in:

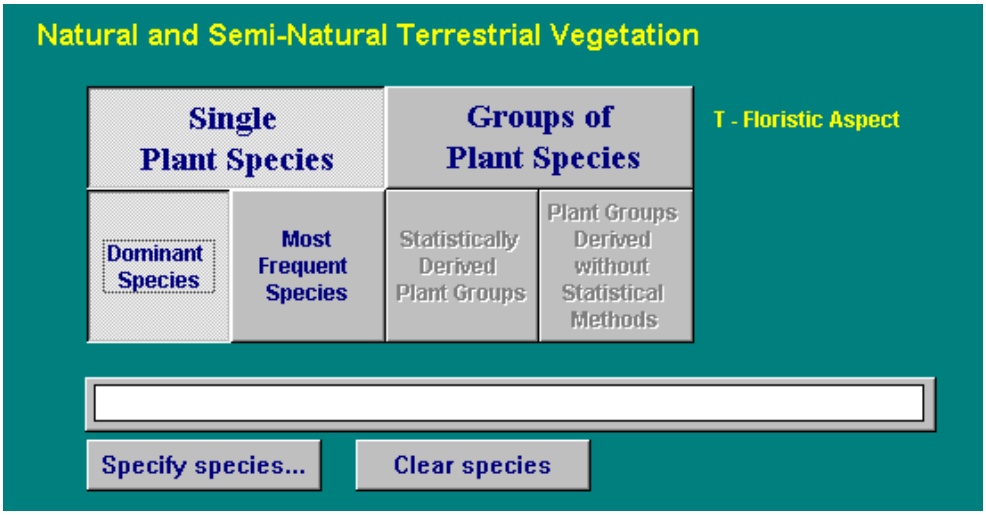
- a separate code added to the string of codes of attributes in the Boolean formula (e.g., Basic Classifier: A3A10B2C1-L2L7**T3**, Modifier: B5);

- no alteration of the numerical code (e.g., 20007-13152 remains unchanged);

- no change in the standard name as the specific technical attribute choice follows the standard name and after any environmental attributes used (e.g., Class Name: Closed High Forest; Major Landform: Sloping Land; Slopeclass: Rolling; **Floristic aspect: Dominant species (Height or cover or a combination of both)**).

The user can go through the levels of the Modular-Hierarchical Phase of certain major land cover classes and build up as many classes as needed. These classes can be stored in the Legend Module, described in detail in the next Section.

FIGURE 18.
Example of the use of the Specific Technical Attribute *Floristic Aspect*.



5.2 LEGEND

5.2.1 Purpose

The main purpose of the Legend Module is to store the land cover classes identified in a hierarchical structure that groups the classes according to the main land cover type. Therefore the Legend usually contains only a subset of the Classification, that is those classes which are applicable in the area (to be) interpreted or mapped.

In addition to providing a hierarchical structure, the Legend also offers capabilities to display, edit and add user-defined attributes to a land cover class. It provides standard descriptions for the classes identified and the classifiers used, and all this information can be exported in various formats.

Because in the Legend the classification is applied to a specific area, *Mixed Mapping Units* can be formed. A Mixed Mapping Unit can comprise two or three classes from the same major land cover type, or two or three classes from different major land cover types. The order of the classes in a Mixed Mapping Unit reflects the dominance in the mapping unit (see also Section 2.5).

5.2.2 How To Create A Legend?

Land cover classes are defined in the Classification Module. A Legend is created by storing these land cover classes in the Legend. To store a class defined in the Classification Module, the "Write Class to Legend" button needs to be clicked on in the action panel of the Classification Module (see Section 4.1), upon which a sub-menu is shown (Figure 19). This sub-menu questions the user whether the class is a "*Single or Mixed Unit?*". The following choices are available, either

- clicking on the *Single* option stores the class defined in the Legend and the user can define the next new land cover class; or

- clicking on the *Mixed* option makes the program keep the first class defined in memory and await definition of the second and/or third component of the Mixed Mapping Unit.

- If the second land cover class is the ultimate component of the Mixed Mapping Unit, the user should then click on *End Mixed*, but if there is a third component the user should click on *2nd Mixed*.

- To define a third, and final, component of a Mixed Mapping Unit, the third land cover class needs to be defined, followed by clicking on *End Mixed*.

- To annul storage of a land cover class in the Legend the user can select *Cancel*, or, if the second or third component defined should not be written to Legend, the same button can be used. However, by annulling this component, the system still expects definition of the second and/or third elements.

The *Help* button gives further information on which option to select in case of writing a class to the Legend.

FIGURE 19.
From the Classification Module to Legend: window in which user has to select whether or not the defined land cover class is part of a *Mixed Unit*.

In the current classification (and its derived Legend) a *Mixed Unit* is defined as a **mapping unit where more than 25 percent of the dominant cover belongs to another land cover class**. The dominant land cover class is always the first class mentioned (e.g., Closed Forest/Herbaceous Fields indicates a Mixed Mapping Unit of forest and fields where the forest is the class covering the bigger portion of terrain, more than 50 percent, while the agricultural fields cover at least 25 percent of the area, but less than 50 percent).

The Mixed Mapping Unit is then stored in the Legend. The user can continue to define other land cover classes or switch to any of the other program modules.

There are two ways to enter the Legend Module, either:

- directly from the *Main Menu*; or

- from the appropriate button of the Action Panel in the *Classification Module*.

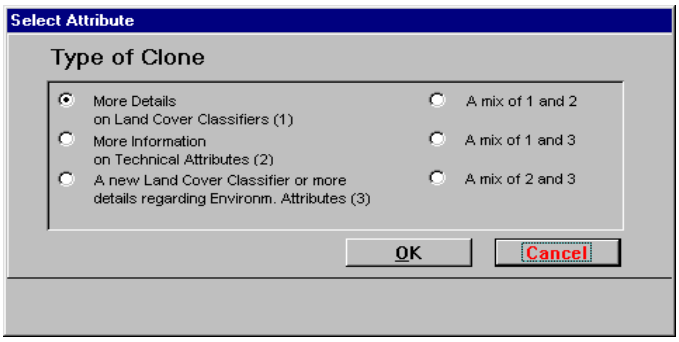
In the Main Menu there is a button which leads the user directly to the Legend Module. However, if no land cover classes have been defined in the Classification Module and subsequently stored in the Legend, the Legend will be empty.

From the Classification Module there is a special button to go directly to the main Legend menu, from where the various options can be chosen, as explained below.

5.2.3 Add User-Defined Attribute

Land cover classes can be "cloned" in order to add some specific user-defined attributes to the standard land cover class selected. This allows the addition of more specific and user-oriented attributes while maintaining a standardized land cover class. The user may want to further define a classifier and/or attribute already used, or the user might want to add a new attribute. A standard set of options is provided (see Figure 20).

FIGURE 20.
Window with the options for definition of the *Type of Clone* in order to add a User-Defined Attribute.



In order to clone a standard land cover class and add a user-defined attribute, follow the steps below (an example is shown in Figure 21):

(1) Identify the land cover class to be cloned in the *Identify class to be cloned* box.

(2) Click on the button *Select*.

(3) A window with the *Type of Clone* opens in which one option needs to be selected, followed by clicking either *OK* to accept or *Cancel* if the operation needs to be cancelled. The option selected will add a figure between brackets to the coded string of classifiers of the class (e.g., 20007-13152**(3)**).

(4) The cloned land cover class is shown in the lower part of the screen.

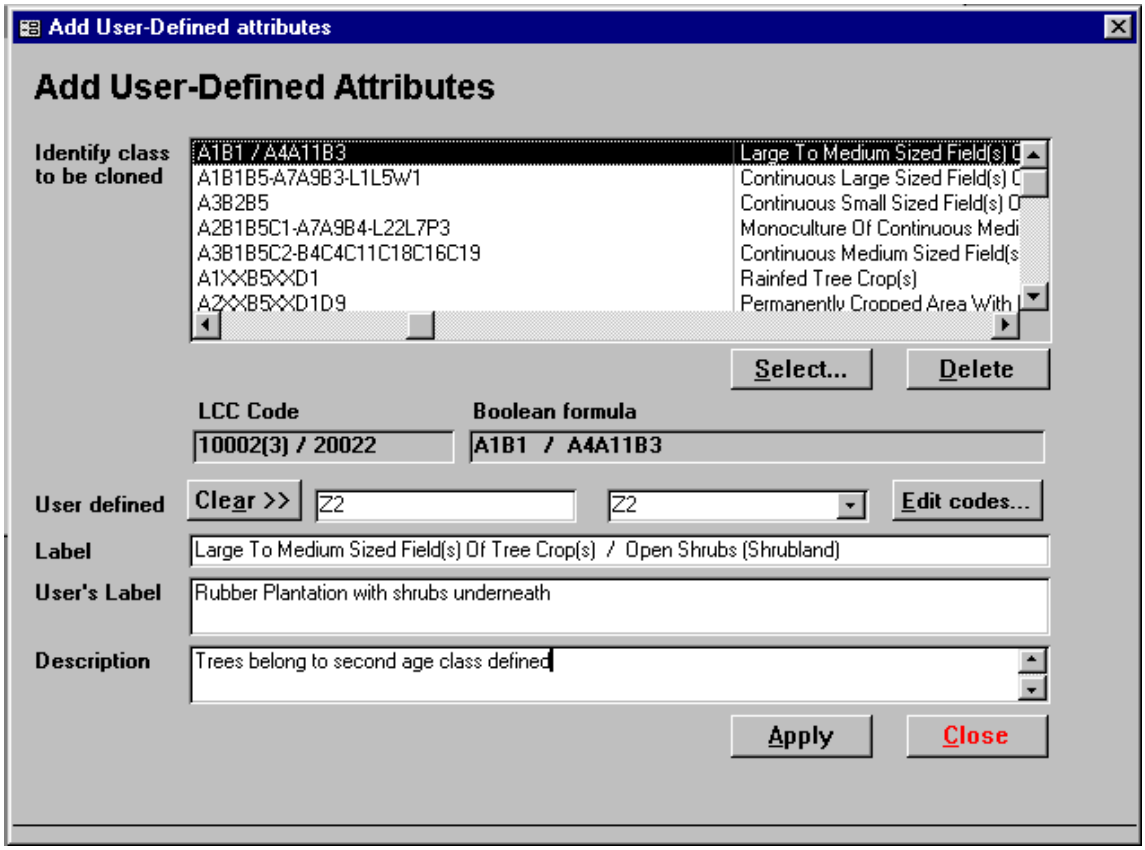
(5) Type the attribute to be added in the *User's Label* box and a description in the *Description* box, if any.

(6) Press *Apply*.

(7) A pop-up message with *Cloned legend successfully recorded* will be displayed. Press *OK*.

(8) Press *Close* when no more classes need to be cloned in order to add user-defined attributes.

FIGURE 21.
Example of Legend *User-Defined Attribute* within a mixed class.



5.2.4 Display

In Display, the classes contained in the Legend will be displayed in a pre-defined hierarchical structure (Figure 22):

(1) The land cover classes defined are grouped under the main land cover type they belong to, and according to the *Structural Domain* within one major land cover type (e.g., *Natural and Semi-Natural Terrestrial Vegetation* with the structural domains *Forest*, *Woodland, Thicket, Shrubland*, *Grasslands* and *Lichens/Mosses*.)(Box 2 and Appendix B).

(2) Within one domain, classes are hierarchically ordered according to the level of classifiers used.

(3) Three items are displayed vertically in the same column: (1) the numerical code, the *Map Code*, of the land cover class; (2) the string of *classifiers* used; and (3) the *Land Cover Class* name.

(4) The column *User's Label* will be displayed as an empty column unless a label has been added by the user in the Legend – Edit function.

Mixed Mapping Units will be displayed under the Structural Domain *Mixed Class* under the major land cover type of the first, and therefore dominant, element of the class.

FIGURE 22.
Example of Legend *Display*.

#	Structural Domain	Level	Map Code *Classifiers* Land Cover Class	*User's Label*
Natural and Semi-Natural Terrestrial Vegetation				
14	Forest	1	20007-13152 *A3A10B2C1-B5* Continuous Closed High Forest	
15		3	20259 *A1A10B1XXXXF1* Closed Woody Vegetation, Single Layer	
16	Grasslands	3	21315-13121 *A2A11B4XXE5F2P5F10G2-B15E7G5* Open Medium To Tall Herbaceous Vegetation With High Trees	

BOX 2. **MAJOR LAND COVER TYPE WITH THEIR STRUCTURAL DOMAINS**

A11. Cultivated and Managed Terrestrial Areas	Tree Crops Shrub Crops Herbaceous Crops Graminoid Crops Non-Graminoid Crops Managed Lands
A12. Natural and Semi-Natural Terrestrial Vegetation	Forest Woodland Thicket Shrubland Grasslands Sparse Vegetation Lichens/Mosses
A23. Cultivated Aquatic or Regularly Flooded Areas	Aquatic Or Regularly Flooded Graminoid Crops Aquatic Or Regularly Flooded Non-Graminoid Crops
A24. Natural and Semi-Natural Aquatic or Regularly Flooded Vegetation	Forest Woodland Closed Shrubs Open Shrubs Grasslands Sparse Vegetation Lichens/Mosses
B15. Artificial Surfaces and Associated Areas	Built-Up Areas Non Built-Up Areas
B16. Bare Areas	Consolidated Areas Unconsolidated Areas
B27. Artificial Surfaces and Associated Areas	Artificial Waterbodies Artificial Snow Artificial Ice
B28. Natural Waterbodies, Snow and Ice	Natural Waterbodies Snow Ice

5.2.5 Edit

In Edit, the classes comprising the Legend are displayed, placing the elements composing the class in different boxes.

The numerical code and standard name cannot be edited. These are standard elements of a class and are identical for anyone in the world using the system and defining the same class. These elements help the user to trace which class needs to be edited.

The *User's Label* and *Description* are the two boxes in which the user can enter user-defined labels and descriptions. These will be displayed in the *Legend – Display* once entered.

Two buttons are displayed at the bottom of the screen:

- *Delete* to delete a complete land cover class from the Legend; and
- *Close*, use of which stores the new User's Label(s) and/or Description(s) in the Legend and returns the user to the main Legend menu. The *Legend – Display* option can be used to check that the operation has been implemented satisfactorily.

5.2.6 Standard Description

The user is provided with a *Standard Description* for every class defined in the Classification Module and stored in the Legend. This description gives more insight into the classifiers used and the structure of the class than can be inferred from the standard name alone. User-defined attributes are not incorporated in the Standard Description; for an explanation of those, the *Legend – Edit* option should be used.

In the Standard Class Description, classes are hierarchically arranged according to the Structural Domains of each Major Land Cover Type (see Box 2), identical to the Legend Display, and the following information is shown:

(1) The major land cover type with its hierarchically ordered *Structural Domains* followed by the *Land Cover Class Code* (*LCC Code*) and Boolean formula or Map Code (*LCC Formula*).

(2) The standard land cover class name (*LCC Label*) followed by the user-defined label, if any (*LCC User defined label*).

(3) The Standard Description (*Standard Description*) of the class followed by the *User defined description*, if any. This description may be useful in reports accompanying maps in which the classes of the map are described in more detail.

The Standard Description can be printed by selecting *Print* from the toolbar at the top of the screen (Figure 23).

FIGURE 23.
Example of the Legend *Standard Description*.

# Structural domains LCC Code LCC Formula	LCC label *LCC User defined label*	Standard Description *User defined description*
Natural and Semi-Natural Terrestrial Vegetation		
14 Forest A1A10B1XXXXF1 20259	Closed Woody Vegetation, Single Layer	The main layer consists of closed woody vegetation. The crown cover is more than (70-60)%. The height is in the range of 7 - 2m and is not further defined. The vegetation consists of one single layer.
15 A3A10B2C1-BS 20007-13152	Continuous Closed High Forest	The main layer consists of closed forest. The crown cover is more than (70-60)%. The height is in the range of >30 - 3m but may be further defined into a smaller range. The vegetation is spread over the area without intervals or breaks.
16 Grasslands A2A11B4XXES F2FSF10G2-B1SE7GS 21315-13121	Open Medium To Tall Herbaceous Vegetation With High Trees	The main layer consists of open herbaceous vegetation. The crown cover is between (70-60) and (20-10)%. The openness of the vegetation may be further specified. The height is in the range of 3 - 0.03m but may be further defined into a smaller range. The second layer consists of sparse trees.

5.2.7 Classifiers Used

In the *Display*, *Edit*, *Add User-Defined Attribute* and *Standard Description* menu options, the Boolean Formula of the land cover class defined is displayed. The menu option *Classifiers Used* gives the user the possibility to interpret what these code strings mean, as it presents, under the headings of the major land cover types, the key to the codes used in the Legend (Figure 24).

This explanation will be useful in GIS/database queries where the user wants to re-select the data according to a certain classifier or a group of classifiers. Combining numerical codes and the Boolean formulae allows re-grouping according to user-defined queries.

5.2.8 Print

Clicking on this menu option will not invoke a new screen display but will send the created Legend to the printer. The output appears as described under *Display* (Section 5.2.3).

5.2.9 Save/Retrieve

This set of options allows the user to Save and Retrieve the legends created an without exchange facility with other LCCS users. A legend stored in this way can only be retrieved by the same copy of the software program.

- To *Save* a Legend*:* click on Save and a window will open in which the user is asked to type the legend name in the appropriate box. No pathway needs to be entered.

FIGURE 24.

Example of Legend *Classifiers Used*.

Land Cover Classification Legend 18-Mar-99

List of Land Cover Classifiers Used

#	Classifier	Classifier Label
Cultivated and Managed Terrestrial Area(s)		
1	A1	Tree Crops
2	A10	Deciduous
3	A2	Shrub Crops
4	A4	Graminoid Crops
5	A5	Non-Graminoid Crops
6	A7	Broadleaved
7	A9	Evergreen
8	B1	Large To Medium Sized Field(s)
9	B2	Small Sized Field(s)
10	B3	Large Sized Field(s)
11	B4	Medium Sized Field(s)
12	B5	Continuous
13	C1	Monoculture
14	C12	Herbaceous Aquatic Crop (Additional Crop)
15	C16	Herbaceous Aquatic Crop (Second Additional Crop)
16	C18	With Overlapping Period
17	C19	Sequential Period
18	C2	Intercropped
19	C4	(Two Additional Crops)
20	D1	Rainfed Cultivation
21	D3	Irrigated
22	D8	Fallow System
23	D9	Permanently Cropped Area
24	S0610	Grapes (Vitis vinifera)
25	S0620	Pistacio (Pistacia vera L.)
26	S3	Cereals
27	S6	Fruits & Nuts
Natural and Semi-Natural Terrestrial Vegetation		
28	A10	Closed > (70-60)%
29	A11	Open (70-60) - (20-10)%
30	A2	Herbaceous Vegetation
31	A3	Trees

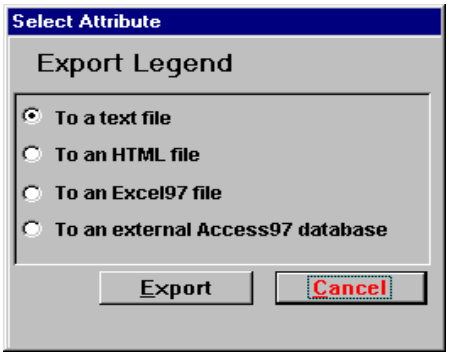
- To *Retrieve* a Legend: click on Retrieve and a window will open containing the names of the legends already saved. Click with the mouse on the correct name and click *OK* or *Cancel*.

- The option *Delete* will delete a stored legend.

5.2.10 Export/Import

Clicking on this menu option will invoke a new screen display offering with four choices. This set of options allows storage of legends in specified formats and exchange of legends with other LCCS users on different computer platforms.

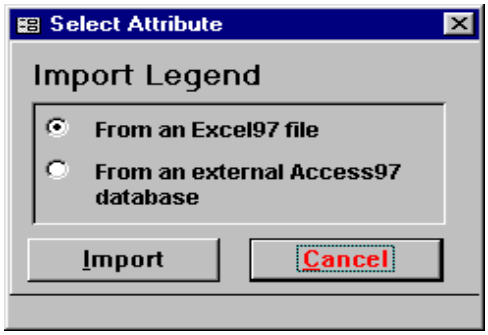
- To *Export a Legend:* click on *Export* and select one of the four options displayed, namely:



The text file will store the Legend as a .TXT file; the HTML file as an .HTM file; the spreadsheet option as an .XLS file; and the external Access database for re-import as an .MDB file.

- select *Export* to export the legend in the selected file format(s).

- a new window is opened in which the user can type the name and select the directory in which to store the legend.



- To *Import a Legend:* click on *Import* and specify whether it is a spreadsheet or an external databse file and type the pathname and filename of the legend to be imported.

5.2.11 New Legend

This menu's options removes the existing Legend, which can be stored in the *Output to* window specifying the directory and name. The default name is *TLegend.txt* and a new Legend can be created as the user is so informed.

5.2.12 Close

This menu option will return the user to the where the user was previously. If the user was in the Classification Module before, new classes can be defined and written to the Legend.

5.3 FIELD DATA

5.3.1 Purpose

In this module, which will become available in version 2.0, the sample site is described and other relevant information can be stored. These data are automatically classified by being translated into the classifiers, modifiers and attributes of LCCS. The sample site can be described using a minimum dataset, a user-defined set or a full set of items. The minimum data set contains only those items needed to meet the requirement to be able to classify the entry according to the Classification System. If the user-defined or customized option is selected, the user needs to choose from the menu which items will be described. These settings can be saved in a file. It will depend on the objectives of a field survey as to which selection will be chosen.

The Field Data Module is designed in such a way that the user does not need to be familiar with the classification concepts. Based on the information observed, the Module will check the various concepts in order to define, for instance, the layering in a vegetation type or the type of cover present.

5.4 TRANSLATOR

5.4.1 Purpose

Existing classifications and legends can be translated into the reference classification. By translating them into the Land Cover Classification System, this system acts as a reference base in which correlation between classifications and/or legends becomes possible.

The Translator Module offers the possibility to:

- translate classes of existing classifications and legends into LCCS;
- assess similarity of classes according to other classifications and legends using LCCS as a reference base;
- compare classes of translated classifications and legends and their attributes, using LCCS as a reference base, at the level of the individual classifiers used;
- to compare two land cover classes of LCCS and their attributes (these may be two classes belonging to the same major land cover type or two classes belonging to two different land cover types) which may be useful when comparing a preliminary land cover class with a validated land cover class in field surveys.

FAO will co-ordinate input of translated classifications and legends for the time being. Major current classifications translated into the system will come as a standard with the software program or will be provided at a later date.

From the Main Menu the user can go directly to the Field Data Module. This provides a short link in the event that preliminary classes need to be compared with final classes derived through field observation.

In the Main Menu the user will also find an option to return to the Main Menu.

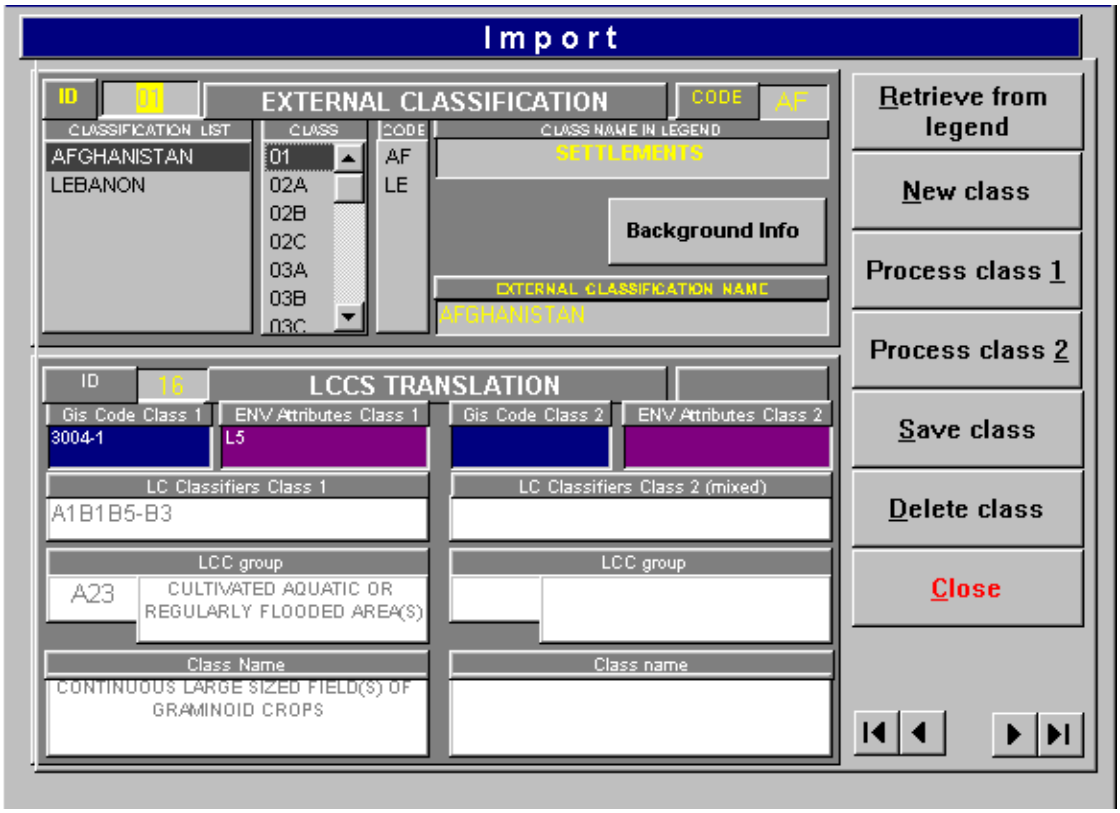
5.4.2 How to translate a classification or legend

Translation of external classifications and legends into LCCS can be done by using the Classification Module and thus creating a Legend (see Sections 5.1 and 5.2) which can be imported in the Translator Module, or by direct input of external classes. In both cases the *Import* option will be used.

Import

If the user has created a Legend containing all the classes of the classification or legend to be imported, these classes can be imported in the Translator Module one by one. In the menu of the Import screen (Figure 25), the option *Retrieve From Legend* should be selected, which displays the screen in which classes from the legend can be imported.

FIGURE 25.
First screen of *Import*.



The *Retrieve From Legend* option will open the Legend *Export to Translator* window. In the box the classes stored in the Legend Module are displayed. How to export a class from the Legend Module into the Translator Module is described below:

(1) Identify the land cover class to be exported to the Translator Module (or Imported into the Translator Module).

(2) Click on *Select as 1st* to display the class in the *Classes Identified* Frame.

(3) Add the user-defined elements from the original external legend to the land cover class selected, i.e., add a numerical ID, type the original name in the box *Class Name in Legend*, type the external legend or classification name in the box *Ext. Classification Name*.

(4) Select *Export*.

(5) This will bring the user back to the Import window.

(6) Select *Process Class 1* to let the system find the corresponding information in the LCCS databases and type an ID in the box above *GIS Code Class1*.

(7) Select *Save Class* to store the class.

(8) Repeat for other classes.

If a class consists of two LCCS classes, i.e., a Mixed Class, the procedure is slightly different. The *Select as 2nd* option should be used immediately after having selected the first class of the mixed unit (Step 2 above). After having completed steps 3 to 6, the option *Process Class 2* should be selected, followed by Steps 7 and 8. The components of a Mixed Class have to be defined as single classes in order to recompose the mixed class in the Translator – Import.

This stepwise procedure allows each individual land cover class in the Legend to be exported into the Translator Module.

The second option is to add the classes, one by one, into the Translator Module using the Import screen display and without using the *Retrieve from Legend* option (Figure 26). A new and unique legend name needs to be added to the existing list and for each class to be imported the user needs to follow the sequence below:

(1) Type a unique ID in the *ID* box; this can be the code in the original external legend or classification.

(2) Type a unique two-letter code to identify this legend or classification (e.g., AF is typed for the Afghanistan Land Cover Legend).

(3) Type the original name in the *Class Name in Legend* box (e.g., Afghanistan).

(4) Type *Background Information* in the appropriate box.

(5) Type a unique sequential numerical ID for the land cover class in the *ID* box of the LCCS Translator.

(6) Type the *GIS Code Class 1* (derived from the Classification Module).

(7) Type the codes of the Environmental Attributes (derived from the Classification Module), if any.

(8) Select *Process Class 1*, the system will now find in the databases the corresponding class name.

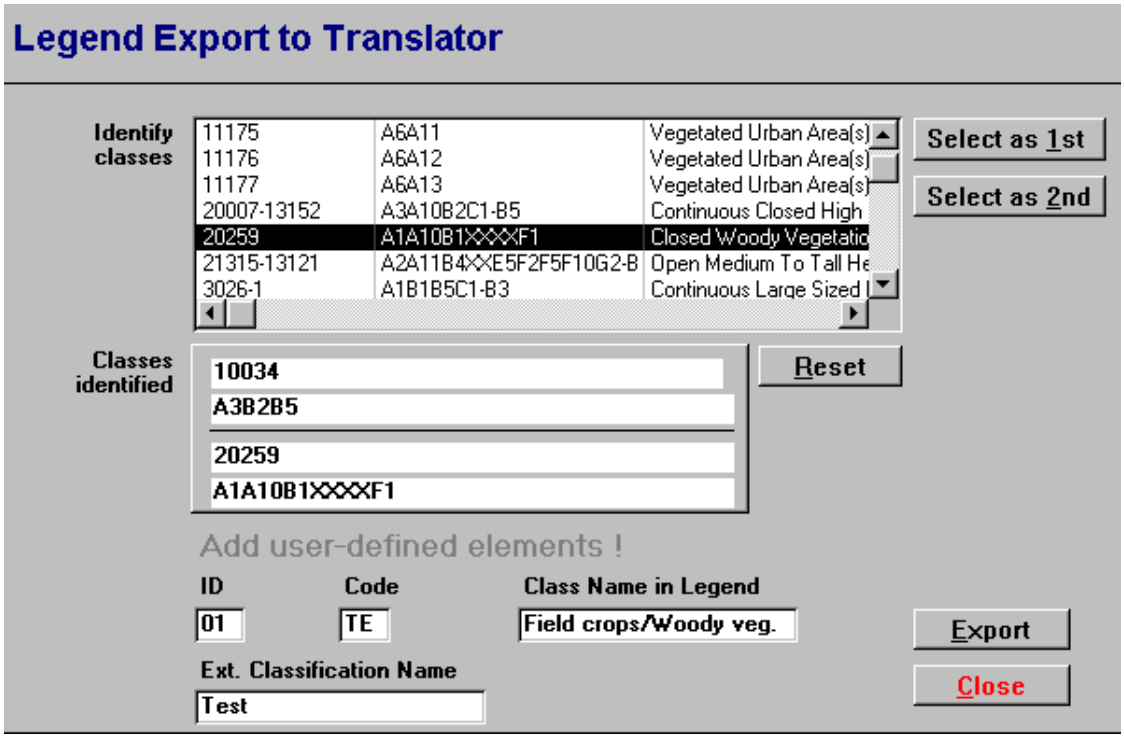
(9) Follow Steps 6 to 8 if there is a second component of the class, using the second set of boxes and click on *Process Class 2* to finish.

(10) Click on *Save* when the boxes are filled with the appropriate labels of LCCS.

(11) Click on *New Class* to import a new land cover class.

This sequence needs to be completed for any class of the external legend to be imported. By clicking on *Close* the user returns to the Main Menu of the Translator Module.

FIGURE 26.
Retrieving individual land cover classes from the Legend Module into the Translator - *Import* facility.



Display Imported Legend

This screen will display the final result of the imported external classification and its translation into LCCS. The user can select to display according to the order in the original classification or legend, or to display according to the order of LCCS. *Mixed Classes* will be displayed according to the dominant, and first mentioned, class.

To display an imported Legend follow the following steps:

(1) Select the classification and press the *Go Next* button (button with arrow pointing to the right).

(2) The imported classes will be shown in the order of the original IDs on the left side of the screen.

(3) The *Show LCCS Legend* will display the translation into LCCS classes.

(4) There are two other options for displays which affect the order in which the classes are displayed: *Original A–Z* follows the order of the imported legend or classification, whereas *LCCS A–Z* follows the intrinsic LCCS order.

(5) The *User-defined Legend Option* will write selected classes to a file.

(6) The *Close* option will bring the user back to the Main Menu of the Translator Module.

5.4.3 Comparison of External Classes

Similarity Assessment

The similarity of individual external classes to other legends or classifications can be quantified. Select the option *Similarity Assessment* in the Main Menu. In the screen display the user has to select the reference class with which the other classes will be compared. A number of threshold settings are provided. These values are stored in a table of correspondence in which the following assumptions have been made:

- the classifier *Trees* is the same whether coming from Natural or Semi-Natural Vegetation or from Cultivated Areas.
- the classifier *Herbaceous* comprises Graminoids and Forbs, or Non-Graminoids, therefore the threshold has been set at 50 percent. The same applies to Woody.

To make a *Similarity Assessment* of two classes (an example is shown in Figure 27):

(1) Select the *Classification Name* of the legend that should provide the Reference Class.

(2) Select *Classes* and highlight the appropriate class.

(3) Click the Reference Class set of arrows to get the selected class in the Reference Class box.

(4) Click the *Compare* button.

(5) Click on the *Reference Class* button and the class selected will be shown on the left side, together with its classifier and the options used.

(6) Select *Empty Report* and press *OK*.

(7) Select the legend or classification to be compared.

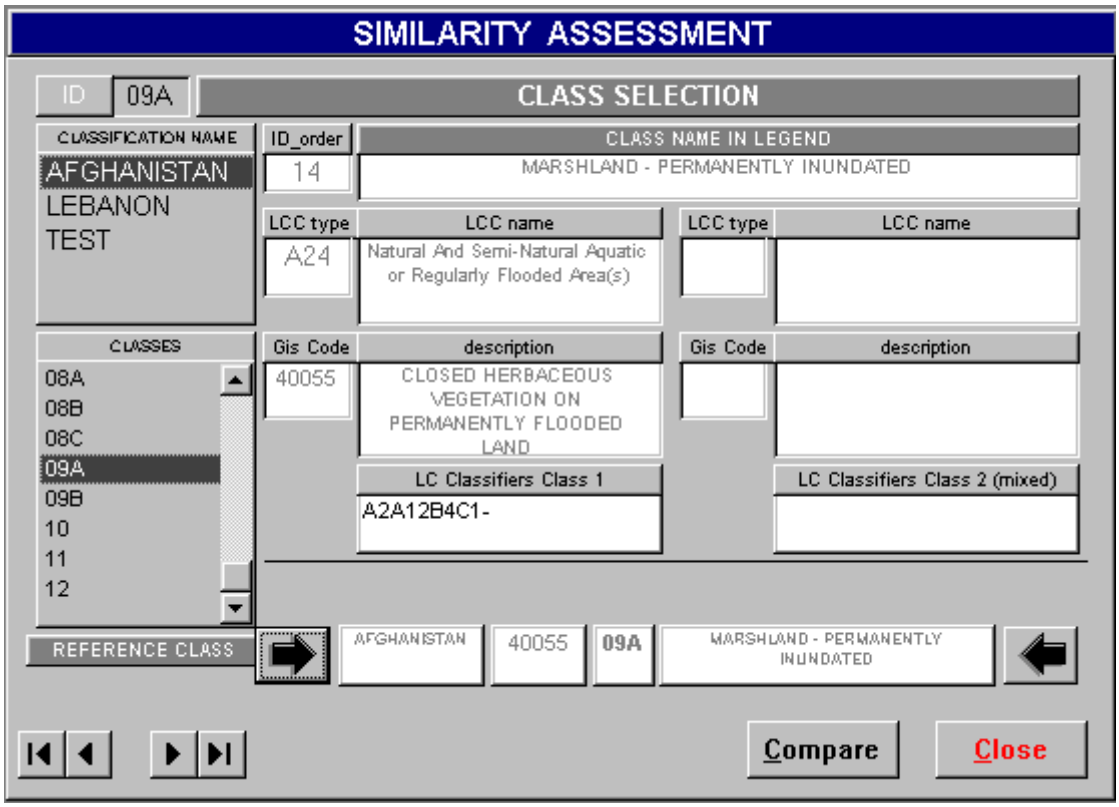
(8) Set the threshold values. Two groups are distinguished: (1) to set if the first classifier should be the same; (2) to set the threshold value of the similarity.

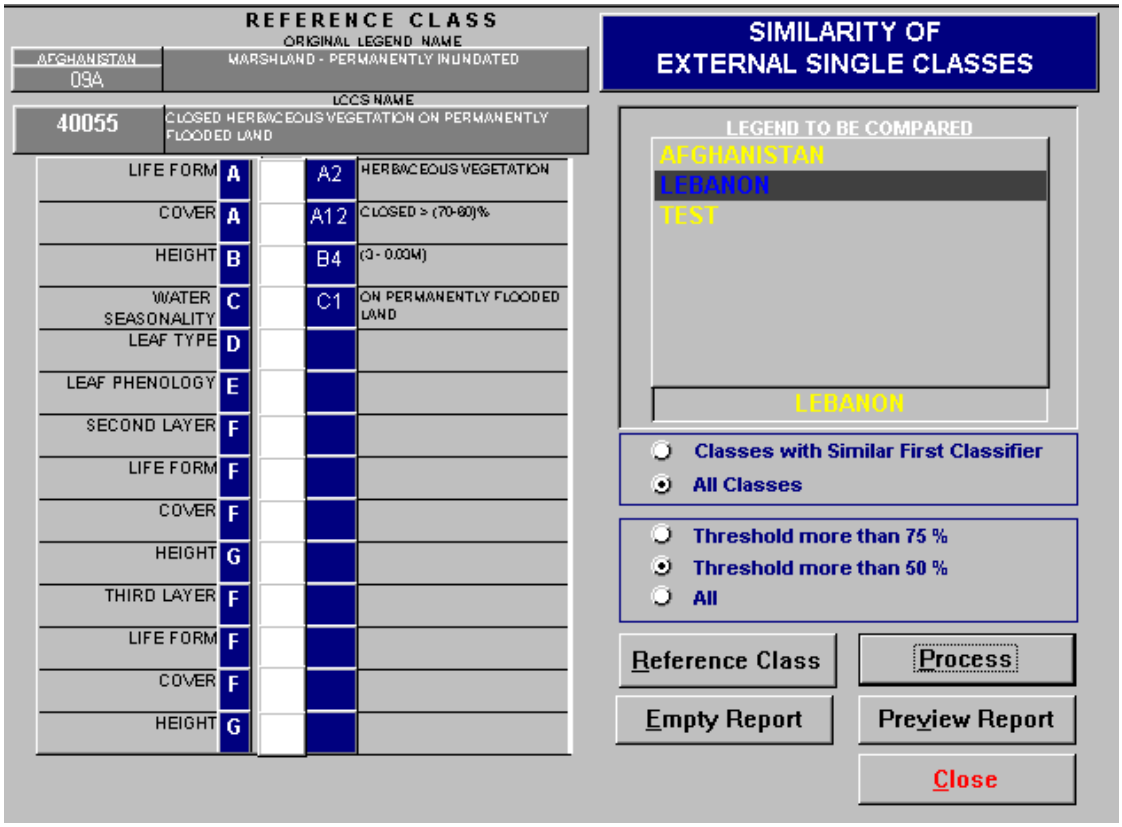
(9) Click *Process* and the assessment will start. A pop-up message will be displayed when the assessment is completed.

(10) Select *Preview Report* and a report will be shown showing the Reference Class, the legend or classification selected for similarity assessment and the results, namely the classes and the similarity value.

(11) Select *Close* to return to the Main Menu of the Translator Module.

FIGURE 27.
First screen of the *Similarity Assessment*, in which the reference land cover class is selected and second screen in which a number of options need to be selected.





Comparison of External Classes

Once classes have been translated into LCCS, the system can act as a reference base for comparison. Individual classes can be compared at the level of their classifiers and attributes, though only those which are provided by the system; user-defined attributes will not be considered. By selecting the option *Comparison of External Classes* from the Main Menu, a screen will be displayed showing the translated classification available or legends and their class codes. By selecting a classification by clicking, and a class by clicking, the boxes with Class 1 and Class 2, if appropriate, will be filled. The arrows allow the user to select either of the two classes as the reference class. Selection of a second class of the same classification or legend, or a different one, followed by putting the selected class in the right box of class to be compared allows the user to go on to the next screen where the actual comparison will take place. Clicking on the button *OK* will bring the user to the comparison screen. Click on *Display* and it will show the two classes and their classifiers; clicking on the button *Compare* will activate the comparison. The comparison will take into account all the classifiers of the class to be compared with those of the reference class. The following colours may be displayed:

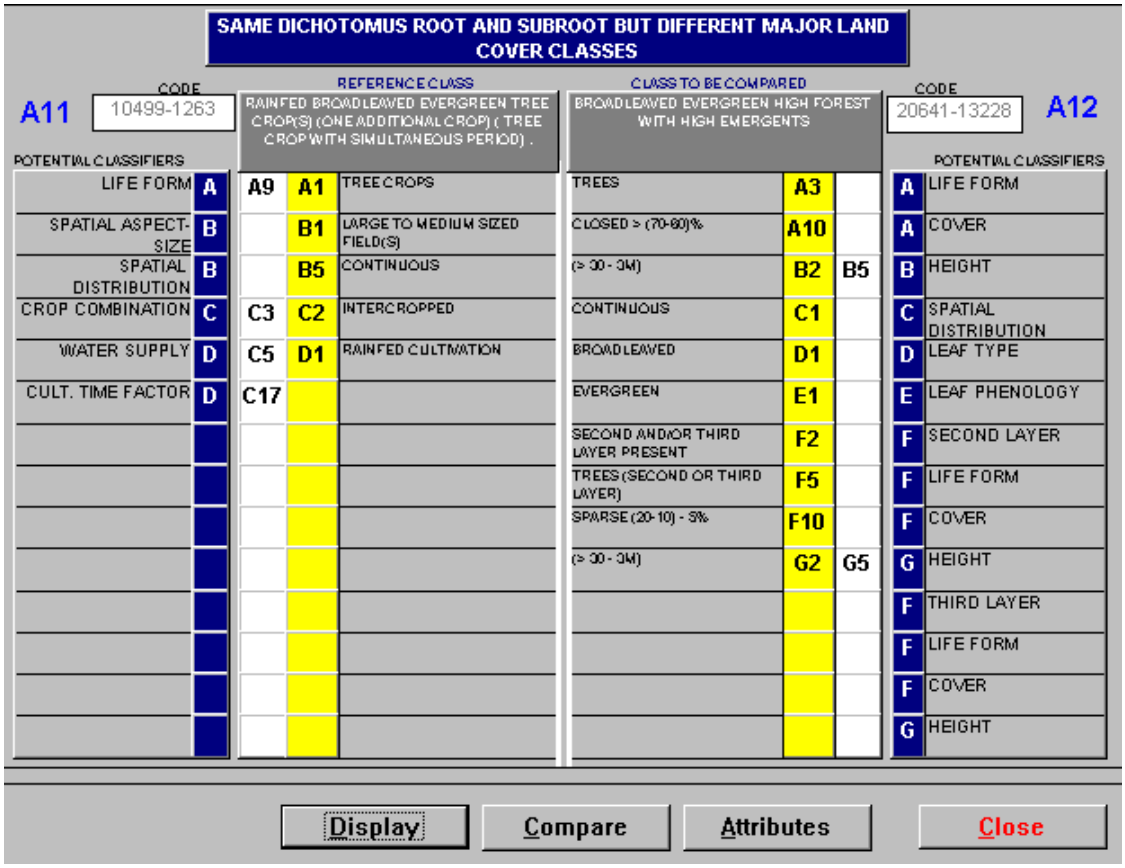
- blue: from the same classifier, the options selected are identical.
- red: from the same classifier, different options have been selected (e.g., from the classifier *Life Form* one class contains the option *Trees* and the other *Non-Graminoids*).
- Yellow: the two classifiers are different and comparison does not make sense, or only one of the two classes contains this classifier.

The same procedure can be followed for comparison of Environmental Attributes, if any, by selecting the *Env. Attributes* option.

5.4.4 Comparison of Two LCCS Classes

Two classes of LCCS may be compared to one another at the level of the classifiers and attributes used. Such a comparison may be based on a class defined in a preliminary interpretation and the other one derived from field observation. By selecting *Comparison of Two LCCS Classes* from the Main Menu a screen is invoked in which the Class codes of the two classes to be compared should be typed, or the most recent data entry of the Field Data Module is displayed and the user has to fill the box with the class to be compared. The *Reference Class* and *Class To Be Compared* can also be entered manually by typing the correct codes in the appropriate boxes. The same set of screens will thereafter be displayed as described under *Comparison of Two External Classes* (Section 5.4.3). Figure 28 shows an example of two external classes being compared.

FIGURE 28.
Comparison of two external classes using LCCS as reference classification system.



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ACRONYMS AND ABBREVIATIONS

AGLS Soil Resources, Management and Conservation Service (FAO)

DIS Data and Information System (IGBP)

GIS Geographical Information System

IGBP International Geosphere-Biosphere Programme

LCCS Land Cover Classification System

SDRN Environment and Natural Resources Service (FAO)

USDA United States Department of Agriculture