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What is land cover?

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Abstract

Much geographic information is an interpretation of reality and it is possible for multiple interpretations to co-exist. This is unproblematic for the research community but, as the numbers of users increase through initiatives resulting in data integration on an unprecedented scale, such as E-science and GRID, issues of information meaning and conceptualisation become more important. We explore these issues through the mapping of land cover and the variety of conceptions of land cover features that may be held by actors in the creation, distribution and use of the information. Current metadata does not report the wider meaning of the information categories in terms of the decisions that were made and by whom in specifying class conceptualisations.

1. Introduction

Truth, as in a single, incontrovertible and correct fact, simply does not exist for much geographical information (GI); rather information is frequently interpreted from personal and group conceptualisations of the world and geographical data are mapped into those conceptualisations. Thus land cover information is inherently subject to indeterminacy and relativism. Herein we argue that as the number of non-specialist users of GI increases and spatial data is used to answer more questions about the environment, the need for users to understand the wider meaning of the data concepts becomes more urgent.

There are a number of current trends that contribute to the significance of this situation:

- First, initiatives, which originate from policy and computing developments, are promoting increased (public) access to spatial information with the aim of informing decision-making about the space in which people live. An example is the EU INSPIRE project which seeks to make available "*relevant, harmonised and quality geographic information to support formulation monitoring and evaluation of Community Policies*" (http://inspire.jrc.it/home.html).

More recently, the development of the computing Grid is providing *"pervasive, dependable, consistent and inexpensive access to advanced computational capabilities, databases, sensors and people"* (http:// www.escience-grid.org.uk). That is to say that in the area of databases, the Grid has broadly the same objectives as the Spatial Data Infrastructure (SDI, INSPIRE in this case). Because of these initiatives, as well as the increasing ease of digital data transfer and a wider acknowledgement of the spatial component of much data, the number of GI users continues to increase.

- Secondly, many users are interested only in the (digital) map. Fisher (2003) documents the shift away from extensive reports accompanying the mapped information as metadata and comments that "fewer than ever [users] are even aware of the existence of the survey report" (p315).
- Thirdly, potential users do not have to go through lengthy processes of data selection involving dialogue with the providers, nor do they often have to go through the time and expense of capturing the data through abstraction and digitizing. Rather they are able to transfer the data to their local system over the Internet or from local high capacity storage devices. Therefore strong financial incentives exist to use the readily available digital data in preference to any other source. If the data is shown to be completely unsuitable for a particular analysis, then the user can search for another source.
- Finally, current metadata standards (ISO, 2003) are adequate to guide assessment of technical constraints on data integration caused by Structure (raster to vector) or Scale (generalizations to lower level classes); but, they convey nothing about the organizational (cultural) or epistemological context which gave rise to the data in the first place.

The net result of reducing the effort required to obtain the data, also reduces the incentive for users to understand that data in a wider sense. One of the consequences of this whole situation is that extensively manipulated *information* is treated as *data* by users who do not fully understand what it represents: its meaning or semantics. They assume that it fits their conceptualisations because of familiar class names and labels that apparently match *their* prototypical categories with those names. Unfortunately for almost all users the available information can only be a surrogate for the specific information they actually require – a situation of which they may be unaware. The consequence of not fully understanding the conceptualisations and specifications hidden beneath familiar class labels are naïve and flawed analyses, a situation that many users may not be prepared to acknowledge, and is hard to document.

Integration benefits can only be properly realised if the differences in data *Meaning* are overcome. Even the simplest concepts can cause problems. For example, in the CORINE land cover map of Europe a "beach" is strictly above the highest astronomical tide, not below it, while in Britain, according to Forest Enterprises a "forest" might not even have any trees on it, and, in both Scandinavia and Eire, land covered in slow-growing trees might not be forest at all. Bennett (2001) discusses the enormous complexity involved in analysing conceptualisations of Forest. Figure 1, constructed from the data of Lund (2004), illustrates different conceptualisation of forest from around the world, based on the physical parameters of tree height and crown canopy cover. Note that in their definition of forest, many countries include land that could be under trees, or where there is a probable intention to replant in the foreseeable future; also that many countries include bamboo and palms in their definition of what constitutes a "tree" and hence a forest, although others do not even where those species are common.

In this paper we explore the generic problem of relativism in spatial information using land cover mapping from satellite imagery as an example. The distinction between geographic data and information is described and the link made between information and conceptualisations (~2). Section 3 reviews some aspects of category theory. Section 4 describes the origins of differences in the meaning of land cover classes and their roots in the different communities within remote sensing and in Section 5 we discuss how various meanings are inferred by different communities of users. The social construction of land cover is discussed (~6) before some concluding comments (~7).

2. Geographical Data versus Information

We regard geographical *data* and geographical *information* as separate and distinct phenomena. We define 'data' as the result of measurement of some agreed phenomenon, while 'information' is the result of interpretation, categorisation, classification or some other form of processing.

Measurements of grass height made in the field, records of the number and distributions of plant species, and surveying of the elevation of the ground above a datum are all examples of geographical data. Whilst observer bias and value systems are embedded in the selection of what to measure and how to measure it, a shared conception usually exists such that if multiple observers visit a location at the same time to measure these properties within an agreed protocol, then the value which is reported has a reasonable chance of being the same. Fluctuations in that value are a matter of either the accuracy or precision of the measurement of the phenomenon.

Geographical information, on the other hand, is different. It involves processing, interpreting or transforming data to derive some sort of interpretation. For example, the identification of the cover of a parcel of land as 'Pasture' is information (even if done directly, in the field). It is common for there to be some disagreement over the interpretation, for example the extent, attributes and position of the geographic phenomenon of interest such as Forest.

In providing interpretation the creation of information adds value to data. We can measure the height of a point above Ordnance Datum, perhaps 201m, but without any other "contextual" information the data is of limited value. A visit to the site would allow an observer to interpret the point in the context of its wider landscape and their conceptualisation of it. The observer might identify a mountain, a hill, or a valley, all of which are information classes, and are, for most people, much richer concepts than the height data. In automated processing of geographical information parameterisation is a major issue, and thus, for example, an area viewed as a channel at a detailed scale may be viewed as, a ridge, a slope or even a peak with changes in the parameterising of the scale of measurement (Fisher et al., 2004). Whilst the concept of *channel* is an unambiguous classification at a specific scale, it is not stable over changes of scale.

In the case of land cover information creation, differences between how land cover features are conceptualised has immediate implications. Harvey and Chrisman (1998) described how notions of wetlands were constructed by different environmental agencies in order to manage their policy objectives. Hoeschele (2000) documented the conflict between land cover and land use mapping for the Attappadi district of India. He revealed serious differences in how land is used and regarded by indigenous commercial and subsistence farmers, on the one hand, and by forestry technocrats, on the other. Similarly, working in Rajasthan, Robbins (2001) documented differences in the concept of forest between different users of the land, and actually implemented this difference in a land cover classification of satellite imagery. Fisher *et al*. (in press) suggest that an origin of this problem may be in the confusion in conceptualisation of land cover as opposed to land use.

Many geographic conceptualisations can also change over time for a number of reasons. Comber et al. (2002) showed how the policy arena drove the change in ontology between the 1990 and 2000 land cover mapping in the UK. Similarly, Bowker (2000) showed the influence of institutional politics on biodiversity data, and Bowker and Star (1996) noted that seemingly objective techniques for measuring nature depend on bureaucratic and institutional systems of categorization.

The implication of this situation is that one characteristic of geographical *information* as opposed to geographical *data* is that it is necessarily unreliable; there is no truth. However, accepting the absence of any single truth is not the same as saying that all interpretations are “correct”; for any given application many characterisations can be easily and unambiguously identified as being inappropriate. Thus a plot of land with a house on it in which a family lives would be correctly identified as residential, but it may or may not be urban, or agricultural land depending on the context; how “urban” and “agriculture” are defined and the spatial and thematic resolutions of the classification scheme in use.

Much work in GIS is conducted within an implicit conceptualisation that geographical information and data are synonymous. For data it is possible to make a direct and incontrovertible measurement of the phenomenon or property of interest. The result is that different techniques, algorithms and individuals often derive equally correct but different information from the same data.

3. Categorization

There seem to be two ways to assign objects to categories: estimating “closeness” (bottom-up) or matching characteristics (top-down). In the first case experiments in cognition (Rosch 1978), show that in general people do not match characteristics but instead compare objects to “prototypes”, (“good” examples of a category), an object is assigned to the category which has the “closest” prototype. Unfortunately they may not be able to say how they estimate distance and what constitutes a good prototype depends on the background of the person. In the second case when an object has all the required characteristics then it belongs to that category, and therefore an object may belong to one, several or no category. This is the more common situation in GI.

Therefore, in generating geographical information using the top-down approach, we first need to agree that there is an objective reality that we wish to record, and, furthermore, that we can make precise reliable and accurate measurements of that reality or of properties of the reality (data). To generate geographical information we then need to:

- Conceptualise what it is we want to know about the reality;
- Determine how we are going to divide the conceptual space to separate that concept into categories;
- Decide how the properties may relate to that conceptualisation and the categories; and
- Make this relationship explicit in the form of some procedures or protocols.

Nominally this provides us with a formal ontology for mapping from the observable measurements (data) onto the concepts (information).

The geographic world and geographical categorization, however, is not that simple. Varzi (2001) refers to the “double-barrelled” nature of geographic entities as they are intimately connected to the space that they occupy and also infected by the manner of their human conceptualisation. Furthermore, whilst many (non-geographic) objects have boundaries that correspond to physical discontinuities in the world, this is not the case for many geographic objects. Boundary placement is often problematic (Burrough, 1986; Burrough and Frank, 1996). Smith, in a series of excellent papers has recognised this phenomenon and developed the concept of *fiat* and *bone fide* boundaries, corresponding to *fiat* and *bone fide* geographic objects (Smith, 1995; 2001; Smith and Mark, 2001). Briefly, *fiat* boundaries are boundaries that exist only by virtue of the different sorts of demarcations effected cognitively by human beings: they owe their existence to acts of human decision. Fiat boundaries are ontologically dependent upon human fiat. *Bona fide* boundaries are all other boundaries. They are those boundaries which are independent of human fiat. So whilst ordinary (non-geographic) objects may be closed, having bone fide boundaries corresponding to physical discontinuities in the world, geographic objects may overlap. But even this is not enough, because it still assumes that the definition of object whether fiat or bona fide is relatively uncontroversial. Geographical categories, however, exist in space and react to scale (Fisher et al., 2004) and to the interface between human conceptualisations and the physical environment (Smith and Mark, 2001). Thus categories can depend on the interaction amongst human perception, spatial arrangement and properties or characteristics and can vary fundamentally with scale.

Smith and Mark (1998) commented that geographic categorization is a matter of linguistic and cultural factors. This is because defining many geographical objects necessarily involves an arbitrary drawing of boundaries in a continuum. These boundaries will differ from culture to culture, often in ways that result in conflict between groups. Therefore the boundaries contribute as much to geographic categorical definitions as the elements that they contain in their interiors (Smith and Mark, 1998). Thus we see that the two concepts of a boundary are crucial to our understanding of the world of geography (Smith 2001). This conceptual vagueness not only affects the categorical apparatus with which geographers articulate the world; it also seems to affect the vast majority of the individual objects that geographers talk about (Varzi, 2001).

4. Origins of different meanings of land cover classes

Land cover information derived from satellite imagery provides a convenient illustration of the way information is subsequently treated by users and how the meaning of much geographic information can be ignored. There is confusion in the way that different users treat land cover information, which originates in part from how land cover information is generated. Most users assume that land cover *information* can be treated as land cover *data*.

4.1 Technical, Epistemic, Physics-based

The sensor specification, its resolving power and any image pre-processing executed influence the land cover information that can be derived from remotely sensed data. Thus the nature of the land cover features that can be identified from image data is influenced by the scale of the imagery (Woodcock and Strahler, 1987), the sampling grid (Chavez, 1992), the data captured by the pixel (Fisher, 1997), the sensor's Instantaneous Field of View (IFOV) and in which parts of the electro-magnetic spectrum it records. Commonly scale in remote sensing is a function of the sensor's IFOV which represents the ground area covered by the sensor (Forshaw *et al.*, 1983) and the sensor's spatial resolution (Woodcock and Strahler, 1987). These determine the granularity of the data; the level of detail of the processes or objects of interest that can be extracted at that spatial resolution. Changing the scale alters the granularity of patterns of recorded reality.

Spatial resolution is commonly expressed in terms of pixel size. The pixel may correspond to a mixture of several surface types, and an area weighted average of land surface properties (Fisher, 1997). The precision of pixel values are affected by the interaction of the point spread function (PSF) which may degrade (smoothing and widening the image of sharp features), with the sensor IFOV. These factors can result in blurring of detail and reduction of the dynamic range of the measured values.

Raw satellite data is subject to extensive pre-processing prior to being used for applications. Standard remote sensing textbooks describe the techniques by which remotely sensed data is corrected for geometric and radiometric errors (Lillesand and Keifer, 1987; Richards and Jia, 1993). Both types of error change the relative distribution of brightness over an image or the values of a single pixel (Richards and Jia, 1993). Corrections are made to image brightness and image geometry. Underpinning pre-processing corrections are assumptions that surface features of interest, such as land cover, directly affect the transfer of radiation within the constraints of the sensors' IFOV and pixel size. Verstraete *et al.* (1996) note that the formal relations between sensor data, the properties of the classes and the effects of the state variables of radiative transfer (atmosphere, vegetation, soil, and position, size, shape, orientation or density of the objects) are rarely established. They are assumed and it is unusual to see these assumptions reported (Verstraete *et al.*, 1996): the choice of pre-processing algorithms and control points to correct for haze and geometric distortion are not included in land cover metadata. Land cover information is not only influenced by assumptions about radiative transfer, resolution and scale factors, but also by data pre-processing prior to classification. These issues involved in data pre-processing can be characterised as being *technical* and addressed by a part of the remote sensing discipline that is grounded in *physics* or *statistics*. The *physicists* can be caricatured as ignorant about how data and information are combined to make measurements of the biophysical world; how measurements or data are transformed into information. Yet many data pre-processing factors contribute towards the *meaning* of the land cover data in terms of the features on the ground that can be identified. They influence the nature of data collection or the *epistemology* of land cover.

4.2 Semantic, Ontological, Biology-based

The classification of the pre-processed (corrected) data into land cover classes also influences the nature of the thematic land cover information. Statistical classification of the pre-processed remotely sensed data identify clusters (classes) by their spectral similarity (unsupervised classification) or allocate class labels to pixels on the basis of their similarity to a set of predefined spectral classes (supervised classification). There are different statistical similarities and clustering techniques. These can be broken down into approaches where an object can belong to only one class (hard) and those where an object has a membership, however small, to every class (fuzzy). In addition, most approaches treat each pixel as the object to be classified, while a few use additional information from some sort of "neighbourhood" or patch.

The classification process is dependent on a number of factors and assumptions. First and primarily, that the features of interest on the ground are spectrally similar and can be separated in spectral space. This is not necessarily the case and many workers have reported problems in differentiating between different classes (Wright and Morrice, 1997; Taylor *et al*., 2000). Second, the process requires some biological knowledge to relate the specifications of the image data to the process of interest. For instance pixel size influences information extraction; woodland is inherently a number of trees interspersed with an understory which itself may be a mixture of bare ground, shrubs, herbaceous vegetation and grass (Freidl *et al.*, 2001). When the pixel size is small compared to the crown of a tree the spectral response has a bi-modal distribution (tree or understory). If the pixel is a similar size as a tree crown then pixels are tree, understory or both and considerable spectral overlap might be expected with open classes such as grasses. Third, there is an implicit assumption that the different land cover classes can be clustered in spectral space, and the *N* classes desired will be identified by *N* separable clusters (unsupervised classification). Whilst supervised classifications assume that the data on which the classifier is trained adequately characterises the target classes. Yet land cover class definitions may be determined outside of the laboratory for instance by field survey, and they may not relate to spectral classes (Cherrill and McClean, 1995). Further, a minimum mapping unit (MMU) is often applied to classified data. It defines the lower areal limit for representing homogenous land cover regions. Although the application of a MMU is an additional legacy of cartographic map production to those identified by Fisher (1998), the choice of the MMU will influence the representational detail and spatial pattern of the land cover map (Saura, 2002).

The issues in classification that can be characterised as *semantic* are addressed by a part of the remote sensing community that is grounded in statistics, geography, biology and ecology. Their activity can be caricatured as applying knowledge of how features on the ground relate to the image specifications and the objectives of the study which are often grounded in policy (Comber et al., 2003). Many aspects such as pixel size, supervised classification training data, and image temporal attributes influence the land cover information that can be derived. The work of the biologist determines how abstract conceptualisations of land cover are specified within classified image data: the *ontology* of land cover.

The process of statistical land cover classification from remotely sensed imagery as practiced by geographers is parallel to prototypic classification as described by Rosch (1978). Clusters are identified in a reflectance feature space composed of the different image reflectance bands. Typically vegetation categories are defined by their positions in a feature space of bands. Supervised classification proceeds by allocating each pixel to the class to which it is closest in this feature-space. Effectively the distance between the pixel digital numbers and the typical values for each category in each of the selected bands are combined to generate a set of category membership probabilities for each pixel. This is a probabilistic variant of the prototypic approach to categorization that treats each category as a summary description.

5. Land cover information treated as data

Digital land cover information is transferred from producers to users. For many disciplines the concept of "Land Cover" provides a useful surrogate with which to describe the landscape. Land cover has been transformed into a universal panacea for land inventory due to the ease of data transfer and the increased use of spatial data in a range of different disciplines. The land cover information becomes a boundary object in the sense of Harvey and Chrisman (1998); at the boundary between responsibilities - land cover information is produced by one group (the producers), and then adopted by a variety of users. The underlying perceptions of the information differ, however, among the various actors according to their disciplinary perceptions. As Hunter (2002) points out, although we may transfer data between databases, "we may find that data in one database does not necessarily have the same meaning as data carrying the same name in another database, or that data by different names in the two databases actually mean the same thing" (p85).

Remote sensing views land cover in terms of spectral properties of objects. Areas of spectral homogeneity are identified and the influence of scale, resolution and classification are generally acknowledged. Analyses of land cover, however, are commonly reported with neither reference to ecological process (Smith *et al.* 2003) nor the ontological meaning of the land cover features, as defined by the epistemology of data processing (Griffiths *et al.*, 2000). In ecology, land cover is defined by the botany of different classes. An example is the field survey components of the 2000 UK Countryside Survey series (Haines-Young *et al.*, 2000), where an area of land cover is delineated by the number and type of specific plant species. On the other hand, soil surveys use the presence of different land covers as an indication of the underlying soil type, while landscape ecology is concerned with relating spatial pattern to ecological process (Forman, 1995). Landscape analyses therefore *are* concerned with how changes in landscape scale, resolution, and classification can have complex consequences for landscape pattern, analysis, and interpretation (Turner, 1989). However, they are not concerned with the origins of land cover (Gulinck *et al*., 2000). In GIS land cover is treated as another analytical layer. A false perception of accuracy may be produced as the precision of coordinates in GIS is greater than the accuracy of the spatial data. Computer Scientists, brought into this arena by the advent of GIS and digital mapping, can be caricatured as considering only an object (pixel or vector) with some attributes that may have a class hierarchy (matching their experience from other applications of computer science). In both cases only the class identity is of interest.

As users, all of the above disciplines can be characterised as not understanding the precise *meaning* of the data in the same way as the data producers nor being able to interpret heuristically commonly found artefacts such as spectral confusions, or boundary issues. Because very few of the stages of land cover information production described in Section 4 are reported, and because for land cover there is no agreed data primitive or natural kind, the following scenarios occur:

- Users assume it represents measurement of some agreed phenomenon that is independent of the mapping process;
- Users accept that the land cover information presented is appropriate for their analysis;
- The implicit conceptualisations in land cover datasets are not always understood by the users; they may use them without fully understanding (or even considering) what the land cover information means in terms of the assumptions that underpin it; and
- Users treat the derived information as data.

In treating the land cover information as data users are implicitly ascribing different meanings to the information according to their disciplinary constraints, focus, or objectives. That is they impose their own interpretations of what land cover should encapsulate relative to the objects of interest. For instance, landscape ecologists are concerned with the impacts of changes in spatial configuration of the landscape and they use the information as if it were data to support this endeavour. They rarely think in terms of land cover primitives and the nature of the data they are using. In computing science data is commonly considered to represent *only* data primitives, blocks of which can be aggregated according to need. In short, different users have different conceptualisations of the land cover. In their applications either they assume their disciplinary primitives are recorded by or nest into land cover information or they ignore the problem.

6. The social construction of land cover

Geographic data necessarily abstracts from a reality or perception of the reality on the ground, through a social and policy process interfacing between the data, the information and its use. The abstraction process is deeply entrenched in the social and political context of the operatives, indeed some work has described the extent to which land cover information is overtly politically and socially constructed (Hoeschele, 2000; Robbins, 2001; Comber *et al*., 2002, 2003), and results in relativist measures of reality. Relativism is multilayered. Some relativism originates in raw data pre-processing for geometric and radiometric correction, processes so common, universal and uncontested that they are not even reported in the derived thematic products, and often poorly reported even for the image products. A further layer originates from partitioning the data into land cover classes.

The implication of the social construction of land cover data is that different agencies will have their own view of the world due to different social contexts. Social constructionism rejects the notion that knowledge can be divorced from social experience in order to access objectively an external reality. Instead it is necessary to understand the constructions (interests, power relations, etc.) rather than trying to determine 'objective conditions' through more data and better science (Jones, 2002). If this view is accepted then the question is "how 'real' are environmental problems when a plurality of perspectives exist?" (Jones, 2002, p. 248). Jones (2002) suggests a middle ground in the realism-relativism debate: to accept epistemological relativism (we can never know reality exactly as it is), while rejecting ontological relativism (that our accounts of the world are not constrained by nature). This position accepts diverse interpretations of a common reality as 'meanings' rather than truths and sees the real world as being culturally filtered as meanings are constructed (Jones, 2002), thus avoiding both the naivety of 'pure' realism and the impracticality of 'pure' relativism.

Whilst social construction introduces the question of the relativism of the land cover, the lack of primitives is in parallel with social scientists, who are much more open about the need to discuss "what we are talking about …". Perhaps with land cover we need to be more open about the assumptions and underlying meanings of the information we record and classify.

The process of land cover feature identification from remotely sensed data is a series of complex processes. Users may be unaware of the influence that each stage has on how data becomes information. Some may be closer to the caricatured physicist others to the biologist. Decisions about whether to use the information ought be based on the interaction between the epistemology of the imagery and the ontology of the derived land cover information, in light of the external influences such as policy and the implied uncertainty and risk assessment for their application.

7. Conclusions

Land cover has been adopted and appropriated by a wide range of users most of whom do not treat it as aggregated socially constructed information but as objective data. Developments in technology (sensors, distribution, GIS) have resulted in extensively available and accessible land cover information. Because a) the information is being used extensively in many national and international mappings, and b) users relate their terminology straight into the information names or concepts without considering the class origins, land cover is fast becoming a "monster". The result is that the more fundamental arguments about "what it is that we are trying to measure" are ignored.

The issues surrounding the various influences that define geographic information raised in this paper are not novel and may be widely known. The problem is that they are not stated. The challenge is to determine how they may be reconciled and whether they need to be reconciled, or whether we persist in diverse one-off classifications with a lack of continuity with implications for notions of standards for data sharing and re-use. If we accept the differences and revel in the variety of the representation there may be implications for legal and policy frameworks which do not admit parallel or multiple representations. It also becomes very difficult to develop methods to reconcile data, in order to implicate and bring decision makers to account.

There is a danger that SDIs and wider computer infrastructural initiatives such as the Grid will result in naïve analyses of spatial data and decision-making will be based on those analyses. This interoperability problem is not acknowledged by the current specifications of SDIs and yet the uncertainties caused by mismatches in understanding and conceptualisation of geographic features between the user and GI can be profound.

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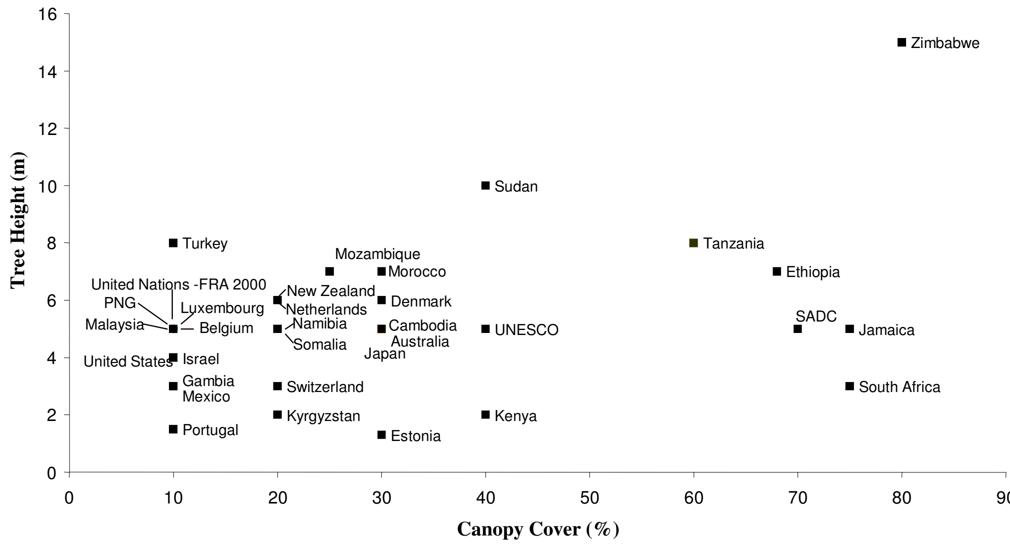

Figure 1. Minimum physical requirements of a "Forest", data from Lund (2004). Note most countries do not actually define their forests in this way.