AN ACTIVE SPATIAL DATABASE FOR THE MULTI-SCALING OF THE NATIONAL PARK OF AZAGNY’S GEOGRAPHIC DATA

BY

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DISSERTATION

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Abstract:

This research aims to design better methods for the creation, management, and display of spatial data used in natural resources management. It applies the results to a test-zone that is the National Park of Azagny located in Southern Côte d’Ivoire (West Africa).

The deforestation that occurred in the Côte d’Ivoire during the 20th century is compelling, and many studies have focused on the deforestation’s social, economic, and political causes. Yet an aspect that remains unexplored is the data used to design the forest management policies. It is not just the lack of data, but rather the quality of data created and the techniques used to create it, which is problematic.

In the beginning of the century, the forest was unknown. Political propaganda generalized the very small amount of data collected to the entire forest. The idea, or rather a mindset, was that the forest was inexhaustible. Exploitation policies did not consider the specificities and weaknesses of the ecosystems, and as a result, the forest’s depletion surprised all of the forest users and policy makers.

Actually, deforestation was not a clear-cut issue. Selective logging and agriculture left many unexploited (or more or less degraded) areas of different sizes that still stand in the landscape. Regeneration within and outside of protected areas still occurs. Nonetheless, the country’s authorities and decision-makers do not considered those forests and the wealth they generate in the country’s assets and exclude them from policies. In fact, another generalization has replaced the old one and created the mindset that logging and agriculture have cleared the entire forest. A forest of 100 ha or less is officially a degraded forest and therefore left to oblivion.

Many studies propose the use of local scales to show evidence of those forest fragments. The problem is that local scales do not give a regional view, and such an approach has been at the basis of the generalizations that governed the forest depletion. Regional views are therefore necessary.

However, existing cartographic and spatial data collection and analysis tools for regional data creation have their limitations, as well. At coarser scales, map documents become cluttered, hard to read. Consequently, mapmakers use generalization techniques, consisting mainly of removing detail information based on subjective criteria and proceeding by trial and error or keep maps at larger scales to improve or maintain readability.

We argue that the issue is not about increasing the scale or reducing the amount of data, but finding a better approach that would port detailed information across scales from larger scales to smaller ones. We propose the use of active databases in Geographic Information Systems. Active database systems allow formulating rules and conditions to select different geometric data types and recalculate attribute values.

We designed a new technique for 1) geometric scaling, and 2) line complexity reduction, 3) dealing with anchor points based only on the value of the scale, and 4) attribute value recalculation by combining initial values. Mapmakers can build such combinations using different strategies. We then integrated these techniques into an active database. Both geometric and attribute value aspects are then managed through a set of rules to decide which geometric data type or attribute value should be assigned or recalculated when defined conditions—geometric and non-geometric—are satisfied.

We applied the system to the test-zone. First, we presented the state of deforestation in the country to show how people created data and how such data has influenced the timber production policies in the beginning. Second, we focused on how on the ground, the spatial scale cutting strategies governed the progression and expansion of deforested land. Third, we analyzed the case of the National Park of Azagny using our newly design system.

As a result, we show that it is possible to transfer detailed information across scales by recalculating data instead of deleting it, based on an event-condition-action strategy. At each scale change, we recalculated the map, and if modifications happened, then we applied some adjustments of geometry type and the attribute values. We could change the geometry based on the scale.

The ecology of the National Park of Azagny was still preserved by the beginning of the 21st century. We show that up to the scale of 1/200,000—which is the official regional scale in the country—it is possible to have a better view of the forest patches, even though official generalization-based data does
not show it. Had those forest patches previously been seen, it is probable that forest management strategies could have been different since those forest patches in the deforested land could help design better policies such as defining corridors or combining land cover types integrating the deforested matrix to design new understandings of the landscape.

New strategies for spatial data creation and multi-scaling are therefore necessary for the analysis of deforested lands. When the size of the entities mapped is small, the integration, aggregation, and redefinition are more pertinent than data removal.

Key words: Deforestation, Geographic Information Systems, Active Database, Multi-scaling, Ivory Coast, Côte d’Ivoire.
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a topic and an idea of the need for the kind of tools the research ambitioned to design. I am still convinced that the strategy the research has built is a way to go. We make decision only with the information we have. This Grant gave me the opportunity to start and construct this research. This has been a very beneficial experience and I just hope that it inspires news ways for better approaches.

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1  GENERAL INTRODUCTION AND METHODOLOGY

1.1  Introduction

1.1.1  Deforestation in the Côte d’Ivoire: Spatial Data and Scale Issues

Cartographic data is frequently used in forest management. In that domain, numbers are often not enough, since for the same size, an area can have various spatial configurations. From their use in simple assessments to the planning of forest resources extraction and renewability, maps are a regular source of information for decision-making. By their capacity to integrate and visualize statistical, typological, and topological data in one graphical document, maps are an efficient mean of data presentation and sharing.

In the Côte d’Ivoire, maps have been used for the assessment, study, and exploitation of the tropical rainforest for a long time. Chevalier (1912) created a vegetation map showing the boundaries and some tree species in many accessible areas. Exploration was not completely exhaustive but allowed mapping many species that have commercial values. Bertin (1918) provided maps showing the location of logging perimeters. Other types of maps served for the location the exploitation areas.

However, there is no particular reason to think that the use of spatial data has helped for the good management of the forest. Teillac (1952) noted that actually the map used to position logging perimeters were not accurate. Indeed, there were no reliable topographic maps until 1959. The maps used before 1959 were made from sparse ground measurements. They were approximate and they lacked accuracy and reliability. Because of the limitations and lacunas of the cartographic documents, some logging perimeters well distinguished on maps actually overlapped on the field and created conflicts. In fact, in many aspects, one can advocate that a misuse of spatial data is one of the foundations of the current level of deforestation.

Deforestation is indeed a very compelling environmental issue in the Côte d’Ivoire (Allen & Barnes, 1985; Mendoza & Ayemou, 1992; Repetto, 1993). According to Lambin et al, (2003) the level of deforestation is below the United Nations critical threshold since less than 10% of the initial forest still exist currently. Logging, agriculture, fuel wood extraction, and other forest resource uses have drastically reduced the area of the initial tropical rain forest to a few protected areas hard to safeguard.
Various studies have focused on the related economic, social, and political aspects (Lanly, 1982; Ehui, 1993; Repetto, 1993, Winter-Nelson, 1995) stressing the lack of regulations strong enough to encourage and initiate sustainable practices. Deforestation was fast and seems to have culminated between 1969 and 1970 the first decade of the independence of the Cote d’Ivoire. However, during more than half a century of forest exploitation, not only regulation did not change but also the system of taxes, fees and exploitation charges was too cheap and incapable to trigger better exploitation practices.

Recently though, a different line of investigations has been rising which pertains more to the accuracy of data collected to describe and present the forest. That line focuses on spatial data creation methods to show how the quality and scale of data have contributed to the mismanagement of the forest.

In fact, the quality of the spatial data used to exploit the forest since the colonial times has always been questionable. Before the mid-1970’s, data consisted in isolated field notes which ignored many aspects of the forest’s internal structure but that were generalized to the entire forest, promoted the idea of inexhaustible evergreen rainforest. At a time were all knowledge was created from ground observations, different terrain obstacles made it hard to visit all the areas of the forest. Simple explorations have later proved not efficient enough at showing the many points of weakness of the forest.

Unfortunately, the idea of inexhaustible forest developed into a mindset that did not aligned with the terrain’s reality but that steered forest management and exploitation policies. Propaganda more political than scientific spread the idea that the forest could be exploited for a century without any harm. There is no evidence that the knowledge acquired during the intense exploitation that lasted more than seven decades was used for better practices. The idea persisted until it became too late to reverse it.

Currently, another mindset arguing a completely deforested land has developed and is feeding controversies. While, many studies are citing the Côte d’Ivoire deforestation as one the most catastrophic disasters worldwide, some others argue that notwithstanding the depletion which has indeed reached a critical level, the situation on the ground is not exactly as portrayed due to human and technical mistakes.

The odd is that this time, nationwide quality satellite data is available along with well-trained geographic information and image processing specialists (Bassolé et al., 2001). What is then the problem?
In fact, the official discourse speaks about deforestation in terms of forest “degradation” instead of forest “disappearance”; it considers forests of less than 100 ha as “degraded” and excludes them from the national forest capital (Arnaud & Sournia, 1980). On the field, deforestation has resulted in a variety of landscapes and a mosaic of vegetation types that are hard to characterize. Forests of different sizes, structures, dynamics and economic importance that are hard to map at the country’s cartographic standard scales -1/200,000 - (Fig. 1) which is more regional, are all assimilated to deforested lands and excluded from spatial data creation policies and management (Achard et al., 2002).

One of the reason of such inadequacy is technical. Map generalization techniques leaves out many details of the terrain in the same fashion the generalization of local observations before deforestation started did. Thus, once again, terrain specificities that could have better informed policy makers were not mapped.

Following that line of reasoning, scientists have argue a scale issue, since usually at regional scales some entities cannot be seen or are hard to map and therefore, suggested a cartography at local scale (Chatelain, et al., 2004). However the problem seems to be more complicated and rather about producing regional scale data with enough details to orient management policy and activities.

Fig. 1: Scale Conventions in the Côte d’Ivoire
On the one hand, in using local scale data only, there is a risk of mistakenly taking local views for larger ones again. Actually, to what extent one could extend the local observations to the entire country is still unknown. Besides, local scale information is not always equivalent to detailed information, the second ultimately depending on choices made by the cartographer. What matters is the amount of details and one way or another, the need for regional views will require syntheses at lower cartographic scales.

On the other hand, regional scales allow mapping larger zones to detect regional tendencies especially in that country where the search for forest creates regional people movement, but cause the reality of the land to be poorly mapped. The ignorance of the wealth of forest in the deforested lands is actually one of the reasons why current forest policies concentrate only on the few protected areas.

The best option is to use a detailed cartography but at regional scale which unfortunately is a case of an unresolved spatial data multi-scaling problem. That situation is the primary motivation of this research, which uses the National Park of Azagny and its vicinities as demonstration site.

The park and its vicinities have become an example of persistent deforestation and failed protection policies. For decades, the area has been under pressure by people seeking forestlands to grow cash crops. To avoid the park’s clearance, the government conducted drastic police operations some of which resulted in strong social tensions. The inefficiency of those actions led to envision more amenable policies and management projects rather embedded and that consider the park in ecological contexts ranging from the sub-continental level of West Africa to the local level of the landforms in the park.

All the devotees of that protection system agree that the biggest threat (the poachers) resides in the deforested vicinities, but none actually undertakes an action in those areas. Decision makers consider forests as the value-makers of the lands but assessments do not mention them. In the absence of data showing the forests, forest managers do not make any policy for the deforested lands, and subsequently, do not take any action. Policies lock all attentions and management resources on the protected areas.

The challenge for creating data that can efficiently inform forest policy-making is therefore about how to show the small patches of forest at the cartographic scale used. Unfortunately, current methods for data multi-scaling even geographic information technologies also have their limits. No proven one exists.
1.2 Data Multi-Scaling Issues In Geographic Information Science and Systems

Many studies involving spatial analysis use data extracted from map documents presented at various scales. Generally, spatial data has two scales: the scale at which data mapmakers collect and analyzed data and the scale at which they present the results obtained from the analysis of data. Usually, they do not state the scale at which data they collect and analyze data on map documents. However, they do mention the scale at which they present their results so that so that the map users can take it to interpret and understand the reality the maps represent. In fact, there is a strong relationship between both scales.

The scale of data collection and analysis often has different meanings. Turner et al. (1989) define it as the smallest distinguishable part of the spatial data set; it is also called resolution or grain and is thought of as the spatial unit at which a process operates in the environment (operational scale). In some literatures, it is termed “support unit” (Bierkens et al., 2000), a plot or defined from its content, the [forest] stand level, the [forest] patch level (Dodd et al., 2006), or more generally, a sampling unit or minimum relevant area. Scale is therefore an analysis unit used to study spatial processes. Usually the choice of that scale depends not only on its capacity to help in making sound analyses, but also sound decisions including the selection of appropriate managerial scales to apply the results of the analyses.

Often, analysis scales govern the choice of managerial scales (Mendoza & Prabhu, 2003). In fact, ideally managerial scales ought to be the same as analysis scales. A good reason is that not every scale is appropriate for natural resources management.

Corwin et al. (2006) recall that even though space is continuous, often only a discrete set of scales is pertinent for its analysis given the interests. Such a set defines the scale range at which ecological patterns and processes can be optimally studied. Aligning managerial scales on analysis scales or vice-versa can therefore be beneficial in natural resources management. A problem is that between both scales, there is the scale at which analysts present the result of their studies.

The results of many studies are presented as cartographic documents. An optimum information level drawn from such works depends on the adequacy that the scale of the map allows to build between the cartography and the reality portrayed. For example, if one assumes a square support unit $S_u$ with area
\[ A(S_a) = \lambda \times \lambda \], then \( S_a \) can be mapped as a square only if \( \lambda \div Rs \) (representation scale) is larger than or equal to the resolution of the display media. A balance between the size of the support unit and the scale of the cartographic representation is therefore important in conveying analysis results. When the analysts do not know that scale, their decisions mostly rely only on the scale at which the results are presented.

It is known that as spatial scale (sampling area) increases, local phenomena tend to hidden by larger ones. Cartography of large-scale phenomena tends to require smaller cartographic scales, result in cluttered documents and therefore, often abandons many details in order to keep the map readable. In that condition, many factors that participate in the daily lives of people and drive the use and depletion of environmental wealth are less obvious, and decision-making rather ignored them. Such situations can lead to the implementation of policies that have proven inefficient or inappropriate.

Scientists therefore have suggested workarounds (Lawes et al., 2000; Loague et al., 1998). For years and across disciplines, many advocates have proposed different ideas condensed under the chapter of map generalization in digital cartography (McMaster & Shea, 1992; Li, 2007). However, the results the suggested techniques give are still debatable and the sources of many controversies because their main principle consists in deleting details (Fig. 2), which reduces the reliability of information provided. Only a very few of those techniques is effectively used by the public. Investigations continue.

![Diagram of map generalization techniques](#)

*Fig. 2: Summary of the Techniques for Map Generalization in Geographic Information Systems*
Our interest to assess appropriately forested lands faces, therefore, an issue. Because of the high fragmentation level, it cannot be a question of eliminating details. The resulting document may be simply blank. Many, if not all, of the official assessments actually ended up producing such “desert-like” land maps. However better alternatives (if they exist) are rather hard to access and it is fair to argue that such a lack of better techniques is one of the foundations of the limitations of the current assessments.

Our search developed therefore into a dual challenge consisting first at designing an appropriate method for data transfer across scales, and then in its application to mapping a highly deforested land. Amongst the corpus of methodologies that could serve as root technique, we opted for active database systems. We argue that a system capable of retaining the details and mapping them based on scale change can solve such a case. In that case creating maps at different scales will not be a single-operation-based procedure, but a multiple-tasks-based process made of routines separated by decision-making stages that need also a level of automation. In that line, active database systems offer many potentials.

1.3 Objectives

The main objective of this study is to design a spatial data multi-scaling method that preserves an optimum level of information across scales to map a highly fragmented forest of the Côte d’Ivoire. The product sought is an active spatial database management system. A system that can select geometry types according to the scale to represent the same entity or compose new entities and eventually reformulate its definition. We will use it to show evidence of forest fragments at smaller cartographic scales.

**Research Objective 1:** Construct a spatial database and fit it with rules to calculate the geometry of the features and their attribute values.

**Research Objective 2:** Construct maps at different scales using the method proposed and compare them with existing documents created with regular cartographic methods.

**Research Objective 3:** Demonstrate the usefulness of the method in terms of management and investigation tool through a cartographic study of the park of Azagny and its vicinities at regional scale.
2 General Methodology

2.1 Steps

The methodology consists in height steps each of them being an autonomous chapter.

1) Construction of a method for map multi-scaling,
2) Construction of a method for line complexity reduction,
3) Construction of a method for shared location control point management,
4) Construction of a method for feature attribute value integration,
5) Construction of the active spatial database for map multi-scaling by bridging the four techniques above and a method for feature integration.
6) A study of how deforestation in the Cote d’Ivoire started and was driven by data quality,
7) A study of how logging operations on the field contributed to the deforestation.
8) A case study to show that innovative methods are necessary.

The whole process is also an argument to demonstrate that map multi-scaling is a multi-task process, as opposed to the idea generally shown by single algorithm techniques. We draw on the manual cartography practices where multiples actions separated by decision-making phases to evaluate the results before proceeding are applied to build the most presentable and instructive document. In that logic, we organized the eight chapters in three parts.

The first part (step 1 to 3) focuses on geometric design, manipulates shapes and boundaries to create geometries at the desired cartographic scale and reduce visual issues related to the reduction of the size of the features. Chapter 1 focuses on the conversion from real world coordinates into representation device coordinates to create a scaled geometric representation. Then chapter 2 reduces the cluttering by eliminating the acute angles that create clusters of pixels. This chapter concentrates only on line vertices in between starting and ending points of multi-lines. Chapter 3 deals with the same problem but at the level of vertices sharing the same location with the vertices of two or more entities. Those points are particular because their modification can result in topological changes. This first part creates a geometric representation and cleans it.
The second part (step 4 and 5) looks for better ways to integrate non-geometric aspects of the representation. We study different ways of attribute value integration and settle on a strategy for value enumeration and mapping in Chapter 1. Chapter 2 wraps up the whole and grounds it on an active database for map multi-scaling. We built a database using Microsoft SQL and Access software to store data (geometric and non-geometric) and created a set of routines to manipulate data. As constructed, the system tries to mimic manual cartographic design in the logic of event-condition-action procedures.

The last part (step 6 to 8) studies deforestation and applies the method so built to a specific case. Chapter 1 recalls the data and knowledge issue to show how inaccurate information shaped the Ivoirian deforestation. We collect different documents from the literature spanning from the 18th century to see what triggered and guided the deforestation. Chapter 2 ports the problem on the ground and tries to translate the deforestation into a scale and spatial dynamic issue. It is also based on a bibliographic study. In that chapter, our interest is no longer about policies but about how loggers behaved in the forest. Chapter 3 uses the case of the Park of Azagny to show how things could have been different if data had been better and to demonstrate the usefulness of our method. Each chapter has a test-zone (Fig. 3)

![Fig. 3: Location of the Test Zones](image-url)
2.2 Data

2.2.1 Documents

We compiled information from the Ivoirian National Institute of Statistics, reports from import/export companies operating in the country, archives of the ministry of agriculture in addition to colonial manuscripts, monographs, and explorer diaries. That data was used mostly for the history of the deforestation. The statistical data available stops at 1985. Some of that documentation, especially for the colonial period, is written in French.

2.2.2 Maps

A map from Chevalier (1912) at the scale 1/3,000,000 gives some information about the vegetation types, the forested lands, and the species in the area at the beginning of the 20th century. The map is in a poor state (a century old), so tightly folded that the areas calculated are rather very close approximations. In addition, the scale of the map has made many details hard to capture with a scanner, especially when they lie on the folding lines.

Topographic maps (I.G.N., 1959) at the scale of 1/50,000 based on the first aerial photography coverage (1956-1957) were used. Base maps are still the master documents of the park of Azagny’s managers. We clipped, geo-referenced and digitized on screen the portion covering the study area.

Guillaumet & Adjanohoun (1971) give some details about the vegetation types along with whether they are under agricultural exploitation or not. That document divides the country in four sheets along the 5°30’W and 7°30’N and is at the scale of 1/500,000, and was obtained in PDF format.

For all the maps, the geo-referencing based on references taken from modern cartographies confronted many precision issues. We made the choice to preserve the internal logic of the documents by aligning the maps first with the frontiers of the country, second with water bodies and lines or shores then on the internal limits of the land use and land covers entity limits. Geo-referencing and digitization was done using the ellipsoid of Clarke 1886 (projection used for those maps), and the result map we re-projected in UTM (WGS84) to calculate the areas.
We obtained maps from the park of Azagny management office. There are copies of topographic maps on which the management has sketched the successive limits of the park since its creation, according to the official documents setting the geographic corners and frontiers of the park.

2.2.3 Image Analysis

The available data consists of aerial-photographs, satellite imagery from Landsat ETM+ (30 meter resolution) from different dates ranging from 1985, 2002, and a 2002 Quickbird imagery (1 m resolution) of a protection zone of the National Park of Azagny. The objective of this classification was to get a reliable dataset. The Quickbird image was classified and the result was used as reference to classify the land ETM image of 2002 (Fig. 4). A few available aerial-photographs also helped in the choice of the training sites. These photographs are at an original scale of 1/50,000.

All of the test-zones were selected from the supervised classification of the 2002 Landsat satellite imagery. All classifications were done using ILWIS 3.3 Academic Version and Erdas Imagine 9.

![Sample Satellite Imagery Used](image)

Fig. 4: Sample Satellite Imagery Used
The success of the research operations was organized as diagrammed below (Fig. 5).

![Research Organization Diagram]

**Fig. 5: Research Organization Diagram**

### 3 Conclusion

The originally forested area of the Cote d’Ivoire is in another dynamic and current assessment methods are proving not efficient enough at capturing and exposing the realm of the terrain. Because of that, management policies are failing to safeguard the portions of forest that could be saved but also at designing alternate solutions for the deforested lands. Deforested lands have potentials. However, spatial data used to design policies does not show it especially at the standard cartographic scales (200,000) of the country. We argue that the problem is not in the sole value of the scale but rather in the methods of spatial data construction at the scale in use since, current methods rely on the simplification of spatial data to maintain map readability at small scales.

This research intends to design a solution for the difficulty encountered in assessing the forested and deforested lands in the Cote d’Ivoire. It is a methodological research that aims to build an automated map multi-scaling method that avoids deleting detailed information when creating maps at coarser scales of the map is coarsened. While current methods are single-task- and detail-elimination-based, the method envisioned is rather multiple-tasks-oriented and detail keeping based. An application to case of the National Park of Azagny and its vicinities will evaluate the method.
References


IGN (1959): Carte de l’Afrique de l’Ouest à 1/50000 (Type Outre-Mer) Tirage préliminaire Côte d’Ivoire. Feuille NB 30-VIII, Abidjan 1a, 1c; Feuilles NB 30-VII Grand-Labou 2b 2d.


PART 1: GEOMETRIC MODIFICATION FOR MAP MULTI-SCALING

An important problem that motivated the design of algorithms for map multi-scaling is that, as the scale of a map is reduced the map becomes hard to read either because cluttered or because features become too small to see. The search for better readability led to the design of algorithms to reduce the number of vertices based on a pre-defined threshold distance whose relationship with the scale of the map is not always clear and often hard to find or to eliminate some features from the map. We argue that the connection, first, between the number of vertices in a shape and the scale of a map and second, between the level of cluttering and the scale of a map is debatable. We think that it is all about the value of the device coordinates which actually determine the location of the vertices on the presentation medium. In this part, we propose a method for map multi-scaling strictly based on the scale of the map and two techniques to solve the cluttering issue.
Chapter 1: Map Multi-Scaling in GIS: A Device Coordinate Filtering–Based Approach

1 Introduction

Map multi-scaling has become a major topic in disciplines dealing with spatial data and using computer-based cartography since the development of Geographic Information Sciences. Reducing the cartographic scale often makes it hard to correctly represent all the details in the map because the quantity of information often clutters the map document and makes it less useful. The details in a map are usually of two types: the first pertaining to the shape and the second to the number of the entities.

To circumvent the problem, many studies concentrated on map generalization in digital cartography have developed different algorithms for map multi-scaling (Douglas & Peucker, 1973; Brassel & Weibel, 1988; McMaster & Shea, 1992; Visvalingam & Whyatt, 1993; Zhou & Jones, 2003; Li, 2007; Mustière & van Smaalen, 2007). Their main principle of those algorithms is to reduce the number of vertices along the features’ boundaries, lines, and number of features. Efforts have not ended.

Muller et al. (1995) discussed many issues related to those algorithms and recently Burghardt et al. (2014) provided more discussion on the same topic. In fact, despite the quality of the techniques proposed, only a few of them have been implemented for use, and a closer look shows that algorithms for point deletion are the most frequently used. In addition, a debatable aspect pertains to the choice of the threshold value that those techniques use to select the elements for deletion, which is rather subjective.

The aspect that is of our concern in this study is the relationship between the variation of the cartographic scale and the need for vertices removal. The reason is that, for representation purposes and constraints, a map (digital or not) is created from the transformation of real world coordinates into device coordinates. That conversion actually simplifies data. Algorithms for point deletion in map scaling are therefore strategies for additional simplification. Our question is what improvement does generalization bring that the transformation from real world dimensions to device dimensions overlooks?

Our argument is that the primary real world coordinates’ transformation actually yields data that, if more efficiently used should suffice at producing readable maps without any further vertex deletion.
The typical conversion operation is actually an entire process of data creation but, that is not followed by analysis before the representation begins. Therefore, there is a missing step in the map construction.

In the following sections, we will revisit the notion of cartographic scale; second, we will use this concept to create, analyze, and filter the data; and third, we will construct and compare maps at different scales and discuss the output with regard to the necessity of performing additional vertex deletion.

2 The Cartographic Scale – Revisited and Discussed

In cartography, generally the scale of a map is understood as the ratio between real world distances and distances on a map. That ratio can take any value even though, usually for convenience, it is rounded to the nearest hundred, thousand or million. It is mostly good for size-related calculations.

In aerial photography-based cartography, often the scale of the map to create is set through the scale at which space appears in the photograph, based on a projection system. There is therefore coincidence between the scale at which data is presented and the scale at which cartography is made. Conversion from real world dimensions to representation coordinates is not needed, even though implicit.

At such a scale, the map created represents a level of abstraction (Fig. 6) performed by the cartographer based on data at the given scale. Choices are made sometimes, even during the photo-interpretation, as to which data model, shape and number of details should be given to each entity or to the entire map document and that also, in regard to how the spatial entities appear in the photographs.

![Image](image-url)

Fig. 6: Reality through Different Abstraction Levels
However rigorous those choices can be, they involve much subjectivity. Visual acuity, experience and even the capacity of the mapmaker to realize stereoscopic vision are important factors that deeply intervene in the differentiation of the spatial entities.

At any time during the cartography, the mapmaker can correct the readability of the map whatever the scale, but more importantly, geometric choices are independent from one another, not only at the level of the components of each entity, but also at the level of the components of the map.

Changing the scale or multi-scaling can be approached in different ways, but an efficient strategy is to bring the original photographs to the desired scale and create the map from them afterward. Thus, the mapmaker again interprets data that is already at the chosen scale. Data is scaled at its source and is not modified. The consistency between the information provided by the maps at different scales is supposed to be maintained by the rigor kept during the interpretation.

In the case of scaling an existing map, often the technique consists of using a reduction device to bring the document to the scale sought and then using various operations to produce a pertinent map. Often, the cartographer just reinterprets the map in the same fashion as it he or she does it for aerial photographs.

Either way, the mechanism is analogous to a process of decomposition, recalculation of the features according to a new scale and re-composition of the shapes of the entities being mapped (Fig. 7).

![Fig. 7: Principle of Geometric Transformation](image-url)
Recalculation is not about distances but about the location of each component of the shapes on the representation medium, based on the scale and the system of projection. Each such component is calculated independently from the other elements.

Often, the cartographer makes geometric choices during the phase of re-composition. The efficiency of the method of calculating the parts of the shapes and of using the scale value to filter out which details “still exist” or “no longer exist” in the map, guarantees the pertinence of the final shapes and the readability of the map. The readability, by the same process, can be evaluated and adjusted all along the cartography. The fact that data is already at the desired scale facilitates the cartography.

In the aerial photograph-based cartography and in a very simple view, the scale is usually calculated as the ratio between the focal distance of the recording device (f) and the altitude of footage (F) (Paine & Kiser, 2012) as in Fig. 8-a. The scale is always approximate since the altitude of the land is not the same everywhere. Generally, an average or mean value is used. The calculation of that average value, even though often managed through conventions (national or international) depends on topographic particularities. It can be based on sea level or be the mean value of different geodetic points selected locally for the project at end. The precision or accuracy of that value will therefore depend strongly on the local topography. Generally, the rougher the topography, the more approximate the value calculated.

![Diagram showing scale determination](image)

**Fig. 8: Simple View of Scale Determination**

We note therefore that the scale is a ratio between values that do not relate to ground distances. It is set in the primary data collection stage and governs every other rescaling. Scaling is about how each
point in space projects on the aerial photographs, and it only presents data to allow cartographic choices. Rescaling uses the same principle and scales data at its source based on an initial known scale. Conversion from real-word coordinates to map coordinates is implicit. The relationship between the scale of a map and real world distances is an equivalence between values.

In digital cartography, the mechanism to calculate the scale can be more sophisticated (Fig. 8-b), using a system of conversion from real world coordinates to screen, or more precisely mapping area coordinates, and also based on a system of projection. The coordinate values conversion is therefore about determining location points, not about spatial configuration, distances or area (even those aspects can be calculated afterward using the same location points as references to construct more complex shapes).

The scale, also simply put, is a ratio such as the one between \([a_1,b_1]\) (measured in device units) and \([a_0,b_0]\) (real world distance) and is essentially a ratio between distances measured on two physical surfaces (Fig. 8-b). Even though that number is device independent, it can take different values depending on how the real world ground distance is calculated.

Actually, the representation device is completely flat, and therefore it is the capacity of the projection and coordinate systems to produce an accurate estimate of the ground measurements that guarantees the precision and reliability of the scale. The impact of the local topography and geographic and altitude references is generally managed through conventional parameters values and coefficients associated with the projection system or the datum.

Data encoded in the mapping device has a meaning that is different from that of the aerial photographs. In fact, usually data encoded in the computer-based cartography system is a representation made of a reality seen at a scale that the automated mapping system is not aware of, but that is in real world coordinates. For example, a scanned and geo-referenced map initially created at 1/50,000 is not known to be at such a scale by the computer-based mapping system. The system only knows the real world coordinates. The consequence of such a situation is that, data in the automated system is assumed to be without any cartographic scale even though there is one.
In that condition, the aspect of the scale at which data has been collected disappears. Because of the equivalence relationship between \([a_1,b_1]\) (measured in device units) and \([a_0,b_0]\) (real world distance) (Fig. 8), computer-based cartography manages every scaling through operations on the distances based on the scale at which the shapes are drawn onto the representation device.

Mapmakers can use different ways to bring a map at a given scale but usually two options are offered. Those options are independent of each other, and it is possible to use both in any order on the same dataset. The internal mechanism to perform each can depend on the implementations.

The first option, which is simpler and actually the most commonly used, consists of increasing or decreasing the size of the displayed graphics without modifying the underlying data. That option uses the functions of zoom-in and zoom-out. The scale of the maps produced that way is often completely independent and different from the scale of underlying data, and the new sizes of the shapes are supposed to be consistent with the projection system used and real-world geometry. The impairment of the visual quality of the map is essentially a graphical or a design issue. The finer drawings the representation device can handle, the better the maps at smaller scales.

The second option, sought by the techniques of map generalization in digital cartography, consists in modifying the underlying data in various ways to produce a map at the desired scale and looks close to scaling data at its source. Many ideas have been developed, but one that has become very common and most often used is to find shapes or parts of a shape that may not be worthy at the envisioned scale, based on a threshold area created by or a threshold distance between consecutive vertices, and to eliminate them. That line of investigation has produced many techniques, each with advantages and weaknesses (Shi & Cheung, 2006), but a major point about these techniques is that how they actually use the scale value to decide the threshold area or distance is rather unclear; further, so is the basis on which the produced map is evaluated as acceptable enough or not. In fact, from the real world presentation, generalization techniques try different values to approximate such a quality representation.

We note therefore that in digital cartography, the scale is the ratio between distances from two surfaces, real world and cartographic device. Conversion from real world dimensions to device-based
dimensions is explicit, at least to create a primary representation. Scaling is how each point in space projects on the mapping medium; however, it proceeds from a data at an unknown scale, encoded in real world coordinates. Scaling by zooming does not present any geometric choices. Generalization aims at presenting data at the desired scale by making pertinent cartographic choices.

Three problems appear in digital cartography. First, data is encoded as without scale even though it is not the case, and since the initial scale is unknown, there is no reference scale. Second, zooming does not allow geometric choices. Third, not only is it unclear how the value of the scale is used in generalization procedures, but those procedures expect to make pertinent cartographic choices without knowing and taking into account how data maps to the representation medium at the envisioned scale, meaning without any reference. There are therefore missing steps in the cartographic design.

In reality, because data is coded in real world dimensions, at every scale change there is a need to convert such data anew into device coordinates, which does not always take place in digital cartography even though it always implicitly does in manual aerial photography-based cartography.

In addition, a step to filter non-pertinent information out of the result of the conversion is necessary. In fact, because of the scale value concentrating many real world units into a single unit on the map, some vertices can end up having the same coordinates. We note that such coincidence or collapsing is not a function of the ground distance separating the vertices, but of the value of the device coordinates in each direction even though such distance can be calculated afterward based on the coordinates.

Given that different vertices can have the same location on the representation, filtering is the operation that ultimately isolates the dataset that is geometrically specific to the desired scale, even though that step does not always happen either in current computer-based cartography procedures.

We argue that it is the absence of those two steps in the cartographic process at each scale change that creates the need for algorithms for point deletion in multi-scaled computer-based cartography.
3 Method

3.1 Principle and Implementation

In contrast to the techniques based on distances or areas, this method focuses on which consecutive vertices are going to be plotted at the same location on the map. It calculates for each shape, the device coordinates of each vertex given the projection system and the cartographic scale, and filters out the sets of consecutive vertices having the same device coordinates to retain one vertex of each such set. We then connect the real world coordinates of the retained points in the same order they appear in the initial shape to recompose the resulting shape as described and pictured in Fig. 7. What matters to us is how each point of the real world projects onto the mapping area.

At implementation, we first took the boundary vertices of the spatial entities in our study area and eliminated duplicated and unnecessary vertices. Unnecessary vertices are those whose deletion does not create a change in the shapes or the topology of the map. Duplicated vertices are vertices that have the same real world coordinates. Second, we calculated the device coordinates of each vertex based on the UTM projection, Zone 29 North and third, we built a filtering method to flag redundant vertices, i.e. consecutive vertices that have different real world coordinates, but the same device coordinates.

Technically, two points at different locations in real world space can hardly have exactly the same device coordinates. A reason is the level of precision used in the digital cartography system. The rounding allowed the use of a tolerance equal to one device unit in each coordinate axis direction.

For every pair of consecutive points, if the difference between the device coordinates equals or is less than the tolerance in both directions, then both points will have same location on the map. In such a case, we retain only the first of them.

Because we are dealing with polygons, we divided each shape into sections limited by anchor points. Anchor points are locations shared by vertices of at least three different entities, or by two entities but located on the boundary of the map. Only the vertices between anchor points have been filtered. Anchor points are exempted from the filtering. In addition, to maintain the rectangular shape of the study area, the vertices located on the boundaries of the map were also excluded from the treatment.
We created a Microsoft Access database along with a set of routines to calculate and flag the sets of vertices with the same device coordinates for each shape section by comparing the device coordinates.

We plotted the map, calculated and compared areas and perimeters, first for a feature that we randomly selected from the area, then for the entire test-zone.

3.2 Test Zone and Data

The method was tested on a map generated from the supervised classification of a 2002 Land-ETM image. The region is a partly deforested land in the South-West corner of the Haut-Sassandra forest preserve in the Cote d’Ivoire (Fig. 9). The northern sector of the region is generally presented as part of the transition land between the tropical rainforest in the south and the savannahs in the north, and the preserve even includes savannahs typical to the West African transitional climate. We determined 10 types of land use/land cover for 1,486 polygons and a total area of 7,003 ha. We chose such an area because of the variety of shapes and sizes of the spatial entities. We assumed that such a variety would help better measure the nature and proportions of the geometric changes induced by the procedure.

From the classified satellite image was traced into polygons without generalization, we extracted the x, y coordinates of the vertices arranged by polygon and exported into the Microsoft Access database.

Fig. 9: Test Zone Location Map
4 Results

4.1 Map Documents

Zoom-in of the initial dataset at 1/75,000

Zoom-in at 1/75,000 after coordinates conversion and vertices filtering

Fig. 10 Comparison between Maps at 1/75,000
The maps on the left were obtained by regular zoom-out. Those on the right were obtained by converting the vertices’ coordinates at each new scale and filtering out the redundant vertices.

Fig. 11: Comparison between Maps at Different Scales
4.2 Discussion

4.2.1 General Observations

The scale change does not necessarily result in a modification of the map. For example, the number of vertices and polygons remain the same—between 1/75,000 and 1/100,000 (Fig. 10). There are therefore scale intervals within which the size of the map features are simply made visually larger or smaller without the creation of any new information. That behavior is similar to the process of zooming-in or zooming-out and can give the same result. In our case, the initial map does not change until approximately the scale of 1/76,000.

There is a strong difference between maps based on filtered vertices and the initial map presented at different scales by zooming out. The maps obtained by zooming out the initial map always look cluttered. In some areas of those maps, many shapes are completely melted in colored patches. The boundary lines and the overall maps look heavier.

Conversely, the lines also look more regular and thinner in the maps made with filtered vertices, even though the line size is the same (Fig. 11). The readability is better with these maps as we coarsened the scale. At smaller scales—1/200,000 and 1/500,000—the differences are such that the maps made with the filtered vertices method look simpler; the shapes are better individualized and the map gives the impression of being made with fewer features even when it is not the case.

We related these aspects to the number of vertices plotted. The initial pixel-based satellite imagery created angular corners that increase the chance of pixel clustering as the scale decreases. We noted that the distribution of the vertices, rather than their number, better explains the clustering and the dark spots.

The level of readability does not therefore always depend on the scale of the data. For example, with a scale less than 1/76,000, removing details only deletes information and reduces the value of the map. We noticed that for a relationship between the level of readability, number of details and scale of the map to hold, at least two consecutive vertices should have the same device coordinates, which is not always the case.
We did not notice an impact of the distance between vertices. In fact, for two sets of consecutive vertices separated with the same distance, one set can end up with the same device coordinates while the vertices of the other set can be of different coordinates. It will all depend at least on the projection system.

If the conversion of real world coordinates generates vertices with same device coordinates, then plotting all of them makes no difference in terms of conveyed information. Plotting all vertices will only overload the map document with redundant vertices. We noted that every transformation that is not followed by filtering the vertices in some way falls in that bias, increasing the cost of production of the map without giving any additional information at the scale sought.

Another aspect is that when consecutive vertices have the same device coordinates, it does not matter which one is used to plot on the map as long as the map-reader presents the map at the appropriate cartographic scale. It is all about how the vertices project on the mapping area of the cartographic device. Conversely, and in such conditions, if the map is zoomed-in, then the view presented will actually incorporate inherently a visual bias requiring recalling the original real world coordinates to fill in the map with necessary information to update the representation accordingly.

The primary scale at which one collects data is therefore very important because it helps set the largest scale at which the representation, if made larger, does not provide more information. There are some bounds or scale intervals within which the presentation is pertinent.

We observed it is possible to perform such a process live when the amount of data is small enough to allow fast processing. In any case, it entails a dual processing: filtering out data when coarsening the scale and feeding in data when the enlarging scale. The initial quantity of data fixes the upper bound. However, the lower bound is strictly technical since it depends on the quality of the data treatment used to create the map at the coarser scales. In our exercise, we deliberately stopped the display at 1/500,000 because it is the scale at which the readability was still possible without extra treatment, in addition to the sole device coordinates filtering.

One advantage of the method used here is that the direction in which the vertices are processed does not have any effect on the result. For example, in the distance-based algorithms for point removal, if
four consecutive vertices are separated by the distance used to select the candidate for deletion, a problem arises as to which point should be deleted first. Whatever direction is used, there can be an orphan point.

An aspect that impacts the entire map is the filtering of the features. We noted that when the number of retained vertices is less than three, the polygon topology excludes the feature from the drawing. We also observed that some features having more than two vertices actually appear like line segments and often are not even drawn when the vertices define two sets of vertices of same coordinates.

The map is therefore filtered first at the level of the vertices to recompose each shape and then at the level of the features that comprise the entire map. Feature filtering results from the number of vertices retained for each shape, but also certainly from how the polygon object has been implemented.

4.2.2 Area Changes

Fig. 12 shows how the areas change as the scale is coarsened. The increase happens mostly for land cover types surrounding other entities. For example, the shrubs surround 208 entities, 168 (181.26 ha) of which are one ha or less. Those surrounded entities are progressively added to the shrubs creating the rise in the variations.

![Area Variations across Scales](image)

Fig. 12: Area Variations across Scales
We note that the variations are larger in the land use types that have a high number of small size polygons (shrubs, crops, fallows, forest and degraded forest) and to lesser extent the villages. At least 55% of the entities for each of those land use or land cover types are one ha or less. However, in terms of proportions of the initial data, those changes do not appear that enormous (Fig. 13).

![Fig. 13: Proportions of Area Loss across Scales](image)

The sensitivity of small areas to the scale coarsening is more visible. For example, 72% of the villages are one ha or less large and 85% are less than 2 ha large, which explains the rapid increase and large area loss of that land use type. We note that the proportions of area loss are not linear but random for each land use or land cover type across scales. One reason for this is the distribution of the polygons. For example, degraded forests lost in area because of their small patches located inside other entities, then gained in area when the other entity types they surround get lost to them.

The combination of how the shape describing each entity’s boundary projects on the map and how the entities are distributed across space therefore determines such game of loss or gain. We note that the actual area does not matter much since two entities with different shapes can have the same area.
Regarding the area, there is no general tendency that seems attributable to scale change. The area of an entity type can stay the same from one scale to another while another entity type will continuously change, gaining or losing. Overall changes affected 48.63 ha, 174.9 ha, 271.41 ha, 328.9 ha, 378.21 ha, and 410.58 ha, representing 0.7%, 2.5%, 3.9%, 4.7%, 5.4% and 5.8% respectively at 1/100,000, 1/200,000, 1/300,000, 1/400,000 and 1/500,000.

![Figure 14: Total Areas across Scales](image)

At each scale, the total area of each land use type remains almost in the same proportions as the value in the initial map, except for the shrub fallows and crops. Those land use types are actually related. Shrubs result from cultivations and are the principal vegetation matrix where cultivations take place. Many cartographies group the three types into one or two categories because of the confusions that occur during the satellite image classification. Such grouping could have reduced the proportions of the changes observed in our test. The impact of the three land use types is much more visible on the graphic (Fig. 14).
Changes that occur in the shrubs represent 51.45% at 1/100,000 and more than 74% of all changes at all the smaller scales tested.

We noted an ultimate case of invariability in the situation in which the shape is formed by four vertices, each of which is an anchor point. Since the treatment excluded anchor points, the area will stay the same at every scale. The shape will disappear from the map when the number of vertices no longer allows drawing it as a polygon.

### 4.2.3 Perimeter Changes

A general increase of the differences in perimeters as the scale is coarsened (Fig. 15). The perimeters become smaller at smaller scales. The reason is the reduction of the number of turns or bends along the boundary lines. As stated before, the boundary, resulting from the tracing of raster image consists of rather serrated-like lines. As the scaling and filtering reduce the number of vertices, a straightening process takes place, which tends to reduce the number of angles and turns along the lines and result in a displacement of the line. That process shortens the lines and increases the difference between the initial and the resulting geometry.

![Fig. 15: Perimeter Reduction across Scales](image-url)
The graphic shows a progressive decrease in the perimeters for all the land use types with two particular cases that are the villages and the waters.

Waters are elongated features. They are only a few and they do not display very complex shape in the area of study comprised of one major entity and two more circular and little ones. The reduction in their perimeters almost stops with the elimination of the first series of raster-based angular boundaries vertices, but more importantly.

The case of the villages (Fig. 16) exemplified how the perimeters and areas can decrease or increase across scales following shape modifications but also how variation can be random.

<table>
<thead>
<tr>
<th>Scale</th>
<th>Map</th>
<th>Initial</th>
<th>1/100,000</th>
<th>1/200,000</th>
<th>1/300,000</th>
<th>1/450,000</th>
<th>1/500,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shape</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Anchor Point)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area (ha)</td>
<td>9.81</td>
<td>9.405</td>
<td>9.27</td>
<td>8.325</td>
<td>6.255</td>
<td>6.975</td>
<td></td>
</tr>
<tr>
<td>Perimeter (m)</td>
<td>1500</td>
<td>1241.09</td>
<td>1170.391</td>
<td>1137.215</td>
<td>1096.772</td>
<td>1114.639</td>
<td></td>
</tr>
</tbody>
</table>

*Scale invariant presentation

Fig. 16: Scale-Based Shape, Area and Perimeter Modifications

In Fig. 16, the change after 1/400000 is because at each scale, the device coordinates of each vertex change. The location of the vertices after the scale-based conversion is not dependent on the proximity between vertices, but on how the projection system positions the vertices based on their location in the real world. We noted that linear shape sections tend to change less. The overall shape in such cases varies more based on the curved sections. The case rises because we are plotting the shapes using the first of the set of redundant vertices. Under the assumption that at smaller scales spatial entities appear smaller, that choice appears as a weakness of the method if not an exception.

Perimeter variations are definitely more noticeable than the area proportion changes. In the test-zone, perimeters decrease up to around 70% of the initial value, and recall that some shapes reduced to single points complete disappear from the map.
4.2.4 Variation in the Number of Polygons

As we coarsened the scale, it happens that some entities reduced to less than three vertices after the filtering. The polygon topology rejects such entities and fills their space with the surrounding ones (Fig. 17). We noticed that some of the entities that the polygon topology leaves out could have three distinctive vertices, but with an area close to zero hectare. Because we plotted each shape without any conditionality of our own, we attributed the rejection to how the polygon object is implemented in the computer-based cartography systems.

![Initial Map at 1/75,000](image1) ![Map at 1/200,000](image2)

(Note: Screen shots not at scale)

Fig. 17: Scale-Based Space Filling

Ultimately, we forced the elimination of all features having an area of zero hectare and/or zero meter perimeters from the database. That procedure could not give any improvement or decrease in the resulting map’s graphic quality. In fact, entries with empty shapes create an inconsistency between the actual number of shapes plotted and the number of entities listed in the database.

The number of features that become too small to represent increases with the coarsening of the scale, and their rejection decreases the number of polygons in the map. We note that the land use types having a large proportion of small size patches underwent a higher decrease in number. Degraded forests, fallows, crops, forests and shrubs having respectively 71.43%, 65.36%, 64.74%, 57.87% and 55.43% of patches of less than 1 ha exhibit the highest change proportions. About 66% of the shapes in the initial
map are equal to or less than one ha in area, and their elimination from the map appears on the chart (Fig. 18). The number of polygons tends to vary less from the scale of 1/250,000 and lower.

We remarked however that shapes of small size that are more circular tend to be eliminated more quickly from the map. Because we generated the initial map by tracing a satellite imagery, all the polygons having less than one hectare in area are squares, whose shape contributes to making them prone to such fast elimination. Elongated features tend to persist longer in the map, taking transitional line shapes.

![Fig. 18 (a): Total Number of Polygons Across Scales](image)

![Fig. 18 (b): Reduction in the Number of Polygons Across Scales](image)
We could also see that the distribution of the number of polygons per land use types can change across scales. For example, in the initial map, there were 76 polygons of swamps and 50 for savannas. At the scale of 1/200,000, there are 47 polygons of swamp but 51 for the savannahs. The initial statistical distribution of the number of polygons per land use or land cover types is not maintained across scales due to the filtering at map level.

5 Conclusion

Map multi-scaling has led to the development of many strategies for vertices elimination along lines and polygon boundaries based on the real world proximity between vertices. Such proximity is independent from the scale. We argued in this study that there should not be such a need, a map is created from the conversion of the real world coordinates into device or map coordinates based on a scale and often a projection system, which do not use such proximity. Such scale-based conversion should suffice to provide a set of vertices pertinent to represent the spatial objects without any further need for point deletion. We proposed therefore a new and different way to obtain such vertices. The method aims to flag and exclude redundant vertices from the conversion and retain the remaining ones based on a tolerance value fixed at one device unit and half. We applied the strategy to produce maps that we contrasted with documents enlarged by zoom-in and reduced by zoom-out. The resulting map documents look less cluttered with readability being highly improved. We also noticed variations in the areas, perimeters and the number of shapes. The areas vary less than the perimeters at every scale. As we argued, the study shows that this procedure produces good results by converting the real world coordinates into device coordinates each time the scale changes, and then filtering out redundant vertices to build the representation with only pertinent vertices. In contrast to the generalization algorithms, multi-scaling consists of repeating both operations—coordinates conversion and vertices filtering—each time the scale changes.
References


1 Introduction

Geometry integration in Geographic Information Systems has been a major topic of map multi-scaling over the last two decades. As the cartographic scale is reduced, it becomes more and more difficult to represent all of the features that comprise the map’s content. The density of the features clutters the map and creates a problem of readability. The need to improve the readability of the map has led to the definition of many generalization and map multi-scaling techniques (Brassel and Weibel, 1990; McMaster, 1987; Egenhofer et al., 1993; Li, 2007; Mu & Wang, 2008).

Three lines of thought that have captured attention are 1) detail elimination along features frontiers, 2) feature elimination, merging or displacement and 3) derived entities composition’ from pre-existing features. The list of approaches proposed is quite long, encompassing ontology (Kulik et al., 2005), database systems (Vangenot, 1998; Rigaux, Scholl & Voisard, 2002), abstraction (Timpf, 1999) and even machine learning strategies. However, implementations are still reduced to only a couple of the techniques. Commercial GIS software still heavily relies on the algorithms of Douglas & Peucker (1973) and Visvalingam & Whyatt (1993). A common trait of almost all the techniques is that they seek to modify the shapes based on a strategy of mandatory vertices elimination to produce simpler lines, which can represent linear spatial entities or the boundaries of polygonal spatial bodies. Shi and Cheung (2006) proposed a performance evaluation of a number of those algorithms for line generalization, and pointed out that two main factors influencing the results of the simplification are 1) the density of the vertices that comprise the line, and 2) line complexity in terms of “convexity, curvature or bending energy.”

In fact, the complexity of a line is not always related to the density of the vertices that according to the authors affects the majority of all the algorithms. A line with aligned vertices is not complex but can be if the vertices are not aligned. The complexity is therefore and a sense about how details are arranged along the line. This study investigates a procedure for line complexity reduction.
A trend appeared, differentiating between strategies that deal with multi-scaling using the capabilities of the supporting database management system and which are grouped under the concept of “model generalization,” as opposed to “cartographic generalization” which refers to methods dealing with the cartographic or visual representation of spatial data (Mustière & van Smaalen, 2007). In that vein, our approach aligns more on the cartographic generalization viewpoint. However, the manipulations we performed in order to produce the better visual aspects may entail a modification of the supporting data.

The main question we ask is how a map constructor actually draws the representation. As an answer, we think that the map constructor uses the world coordinates already transformed into map or device units. That transformation is the reason why the readability of a map is not a problem at every cartographic scale. Map details in that case are the collection of angles created by every three consecutive boundary or line vertices. Thus, as the scale is modified, even though the real world coordinates will not change, their corresponding device ones will. We are therefore going to modify the angles formed by consecutives vertices accordingly until the visual cluttering if any, is reduced.

In the next sections of this article, we will illustrate how we see the problem, describe our strategy and present some example of results we could get using this method.

2 The Problem

The cartographic scale of a map is generally defined as a ratio between real world coordinates and representation coordinates. The representation can be paper-based or use any other drawing medium. As the ratio increases, the condensation of more real world units into one representation unit generates side effects. Some representations can become coalescent, very small and hard to see; conversely, some others can be exemplified. As a result, often the map becomes cluttered and its readability is reduced.

In manual cartography, usually the mapmaker deals with all these issues by a constant rethinking of each situation as it appears during the map construction, with the possibility of continuous adjustments. Such flexibility makes the issues more manageable, but also increases the level of subjectivity and even arbitrariness in the definition, composition and cartography of the spatial bodies under investigation.
In digital cartography, the computer executes routines that run individually or in sequences. In that case, it is very hard to achieve what can be done with the flexibility of a manual cartography. According to Regnauld & McMaster (2007), automated map generalizations are still seldom used because of the difficulty of reproducing styles that can be manually achieved. The question is how the line, either as a boundary of a polygonal entity or a linear entity, is drawn in digital cartography and what causes the reduction of readability. Using Esri’s ArcGIS software, we modified progressively the scale of the display, magnified the output and visually examined a polygon map on screen to try to detect what actually makes the map look cluttered when the presentation scale is coarsened (Fig. 19).

<table>
<thead>
<tr>
<th>Scale</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/7,500</td>
<td>All the corners are clearly visible. Line segments and vertices can be visually distinguished. All the shapes are at their best readability.</td>
</tr>
<tr>
<td>1/25,000</td>
<td>Almost all the shapes are still clearly distinguishable. Two phenomena appear: a flattening (1) and two angles being filled up (2).</td>
</tr>
<tr>
<td>1/50,000</td>
<td>The flattening is accentuated. The original vertices’ location is harder to see in many segments. Some angles are no longer visible (2).</td>
</tr>
<tr>
<td>1/75,000</td>
<td>A rounding appears (3). Flattening (1) and filling are strongly accentuated and the filling is creating a cluster (2).</td>
</tr>
<tr>
<td>1/100,000</td>
<td>Small angles are no longer visible either not drawn or looking like a cluster (2). Rounding (3) and flattening (1) are at maximum.</td>
</tr>
</tbody>
</table>

Fig. 19: Scale-based Shape Cluttering
From the observations in Fig. 19, we note that as the scale is coarsened, angles formed by triplets of vertices either are flattened or filled, which gives clusters on the map. The caricatures show the same shapes without the clusters and look clearer, with the three polygons being less confused. Flattening seems to occur mostly when the original angle is wider, closer to \( \pi \) radian; conversely, the filling seems to happen when the angle is closer to zero radian. It is more the coalescence of the line segments bounding the angles that clutters the map and that depends on the value of the angles defined by consecutive vertices. We mimicked the same progression by investigating angle values that reduce the clustering.

3 Method

3.1 Principle

The flattening looks like an equalization of the device coordinates (Fig. 20). As the scale changes, point B seemingly moves due to a reduction of the Y coordinate. The angle seems to widen.

![Fig. 20: Cartographic Angle Flattening](image)

The same process can be observed for the direction of the X-axis. The application of the techniques makes vertex B less relevant and even completely irrelevant when it becomes close to or completely aligned with the two other points, unless it is involved in another topological relation such as being shared by another entity or an intersection. The flattening by itself does not end up cluttering the map. In fact, it results in a self-detail removal. For example, in Fig. 20, when point A, B and C are aligned in terms of cartographic map coordinates, the angle disappears which reduced both segments into a straight line. Because of that, the flattening will not be discussed any further.
The angle filling rather evolves in an opposite direction because the angle seems to narrow. It is also a more complex case because between points A, B and C, it is harder to discern which one moves towards the other, even though in the end the longest segment remains more visible (Fig. 21).

The angle filling creates clusters made of collapsed drawing sections. In pixel-based mapping, collapsing translates into painting consecutive pixels or groups of pixels (P₁) and (P₂) belonging to two or more different segments or features. The problem is then to find a logical location for each pixel such that the phenomenon does not happen when the scale is coarsened.

We devised a technique whose principle is to modify the angles’ values, making them larger by moving the angle point inward of the smaller angle. Moving the angle point produces an effect of flattening which technically should prevent the clustering. A maximum location for point B would be Bz where the value of angle ABC is π radian (Fig. 22).
The program works as follow. Given a line made of a collection of ordered vertices, calculate both angles at each vertex and retain the smallest. Sort the set of smallest angles in ascending order. Take the smallest and proceed as follow: 1) define its bisector (t) passing by point B; define a perpendicular (p) to the bisector (t), [the second angle bisector] and simulate moving it (translation) along bisector (t) and inward angle ABC. From point B, at each move, the perpendicular (p) to the bisector intersects axes [BA] and [BC] respectively at points d and e. If distance [de] is inferior or equal to two device units, keep moving (p) along (t) and recalculating distance [de]. Else, define location b₁ the intersection of (t) and (p) as the new location of point B. Repeat until distance [de] is superior to two device units.

The value of the angle at point B is then larger or equal to twice an angle with tangent = 1 device Unit / [Bb₁]. Every angular sector of the representation whose angle tangent value falls under that threshold value will be cluttered because filled by the pixels or device units which we want to avoid.

Bz is the furthest location point B can take, the position at which A, B and C would be aligned and the angle ABC = π radian. The decision to consider location Bz as maximum comes from the idea and definition of “detail.” In the schema, the detail is defined by the triangle ABC. Location Bz is the last spot point B can take so that the detail disappears without creating a new one.

We considered two options. The first option is to apply the technique without side effect. The idea is that, for four consecutive points defining two angles ABC and BCF and changing the location of point B can modify the value of angle BCF. The modification can even result in the next angle (angle BCF) already satisfying the angle value condition sought and therefore making the application of the technique to that angle unnecessary. In that case, a choice is to be made as to whether to disregard that angle and move on to the next or to apply the technique to that angle using its original location of point B. The technique can be applied invariably in both cases. However, for this study, we chose the first option. We modify an angle only if necessary. This option allows making the fewest modifications.

The technique was implemented in a Microsoft Access Database. A main table contains the XY real world coordinates of the vertices of all the entities that comprise the map. We constructed procedures to evaluate the triplets of consecutive vertices of each entity. The result was plot with the ESRI’s ArcGIS.
In order to obtain a better computing performance, the map was cleaned before the technique is applied. All duplicated (vertices that have the same real world coordinates and that are consecutive in the enumeration order of the vertices belonging to the specified feature) and unnecessary vertices (vertices whose absence does not change anything in the shape of the feature they belong to) were deleted.

3.2 Test Zone

The test zone is a coastal land in southern Cote d’Ivoire (Fig. 23). The land is an ancient forested area that is currently heavily deforested. The landscape associates a variety of land use and land cover types. We first classified by maximum of likelihood a Landsat Tm satellite imagery from 1986 (30 m resolution) and converted it into a vector map so that it can be edited in a vector-based GIS software. The total area is 1206.25 ha. We chose the area because of the wide variation of land use and land cover types. There are 357 polygons and the minimum area and perimeter are respectively, 0.24 ha and 230 m while the maximum area and perimeter are 424.94 ha and 30,700 m. The smallest feature in the area also has the smallest perimeter. However, the feature with the largest area is not the one with the longest perimeter. The number of features per land use or land cover type is also random, ranging from one to 92.

Fig. 23: Location Map
4 Results

4.1 Map documents

At 1/50,000 and 1/75,000, the map is not cluttered (Fig. 24). The shapes are clearly individualized. At 1/75,000, some shapes are very small. The pixel-based angular shape has disappeared.
At the scale of 1/100,000, the reduction of many features starts to create dark spots in the map. The visual quality is decreased but still much better than in the original map. Angle filling is noticeable especially around small size features. At the scale 1/150,000, the cluttering reappears. The maps, before and after the procedure, look almost the same. The procedure’s efficiency appears reduced and even limited at scales close to or coarser than 1/150,000.

4.2 Discussion

We compare the perimeter and area before and after applying the procedure to examine the differences in length and surface extent of land use or land cover types.

4.2.1 Perimeter Variations

The perimeter variations increase between 1/50,000 and 1/75,000, then decrease (Fig. 25). A reason for the increase could be the pixel shape-based outline of the feature boundaries. At 1/50,000, the grid-like boundaries increase the length of the boundaries in the form of Manhattan distance. All angles are right angles, and the procedure creates lines that are still close to the original. However, at the scale of 1/75,000, the differences are larger due to the generation of more acute angles by the geometric scaling (Table 1).

<table>
<thead>
<tr>
<th>Land Use Type</th>
<th>Scale 1/50,000</th>
<th>Scale 1/75,000</th>
<th>Scale 1/100,000</th>
<th>Scale 1/150,000</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
<td>After</td>
<td>Before</td>
<td>After</td>
</tr>
<tr>
<td>Forest</td>
<td>57,647.08</td>
<td>48,899.16</td>
<td>80,691.94</td>
<td>42,387.78</td>
</tr>
<tr>
<td>Degraded Forest</td>
<td>52,42</td>
<td>44,555.43</td>
<td>71,130.35</td>
<td>37,822.96</td>
</tr>
<tr>
<td>Village</td>
<td>900</td>
<td>774.46</td>
<td>1097.36</td>
<td>661.84</td>
</tr>
<tr>
<td>Crop</td>
<td>11,700</td>
<td>10,270.33</td>
<td>17,567.56</td>
<td>9,311.68</td>
</tr>
<tr>
<td>Fallow</td>
<td>72,667.08</td>
<td>61,787.05</td>
<td>99,639.10</td>
<td>52,923.79</td>
</tr>
<tr>
<td>Barren</td>
<td>2,700</td>
<td>2,293.75</td>
<td>3,285.94</td>
<td>1,894.92</td>
</tr>
<tr>
<td>Plantation</td>
<td>56,62</td>
<td>47,911.34</td>
<td>76,648.70</td>
<td>40,615.29</td>
</tr>
<tr>
<td>Swamp</td>
<td>18,186.24</td>
<td>15,708.47</td>
<td>27,561.71</td>
<td>14,139.09</td>
</tr>
<tr>
<td>Water</td>
<td>14636.24</td>
<td>13,725.12</td>
<td>26,565.53</td>
<td>13,267.21</td>
</tr>
</tbody>
</table>

Table 1: Perimeters (by Land Use Types) of Original and Result Map at Each Scale in Meters
Fig. 25: Proportions of Differences in Perimeters between Original and Result Map

The adjustment of the acute angles to avoid the pixel clustering required moving the angle point to further from its original location. We note at this point, that the result map document generated using this procedure will be impacted by the number of acute angles in the original map (Fig. 26).

Fig. 26: Line Displacement with the Angle Based Procedure (zoomed-in to scale 1/1,500)

Consequently, many land use types underwent a large perimeter decrease such as in the case of the villages and the barren lands. The number of smaller indentations on the boundary lines is critical for the effect of the procedure. As shown in Fig. 26, the procedure progressively alters the feature with the “N”-like shape into a parallelogram. Shape alteration is very progressive through the rounding of angles.
and a concomitant shortening of the line segments. The procedure therefore operates as described by the manual caricatures.

Similar to the line generalization procedures, this procedure also results in shortening the perimeters of the features as the scale is coarsened. This happens because of the decrease of the cosine of half the angle measured on the angle’s bisector. Concomitantly, the perimeter variations also tend to decrease as the scale becomes smaller, which is due to the progressive straightening of the lines.

Unlike the same generalization procedures though, this procedure does not result in scale jumps. Point-deletion-based algorithms for line generalizations create scale jumps mainly because they operate by either deleting points when such points satisfy the preset condition or not. In that case, unless there are points that satisfy the condition at every scale, the procedure is only effective by scale intervals. The current procedure avoids that because the goal is not to delete the point but to relocate it. In that case, the jump cannot happen, since at every scale, it is possible to determine an appropriate location. The line displacement can be therefore slower.

Globally, one advantage we found is the possibility to use clear calculated parameter values to run the procedure. Many of the line simplification algorithms use a user-defined measure. For example, the widely used algorithm of Douglas and Peucker (1973) needs a defined value used as a tolerance to determine which point to delete. The problem that arises is which value actually works best since there are no preset rules to determine the tolerance. In the case of the angle-based procedure, the cluttering is a function of the cosine of half the value of the angle determined by the triplet of points. This relation makes the calculation less subjective since the value is rather imposed by the value of the angle, and probably also but to a lesser extent, by the representation device settings or constraints.

In the end, we noticed the cluttering appearing around scale 1/200,000. That cluttering is actually not related to the intermediate or indentation vertices but by the vertices that are excluded from the procedure.

In fact, similar to many algorithms of line generalization, the procedure does not operate on vertices having a status of “node.” Nodes are generally beginning and ending point of lines. In the
implementation, all points shared by more than two features or located on the map’s boundary and shared by two features are considered nodes and therefore excluded from the processing. As the scale is reduced, those points get closer to one another and generate another level of clustering that this procedure does not resolve. Should the features be taken independently from one another, there would be such an issue.

### 4.2.2 Area Variations

The areas of the land use and land cover type vary little across scales (Table 2). We first note that the change is not linear. The areas decrease or increase invariably from one scale to another. For example, degraded forests decreased in the result maps until the scale of 1/100,000, and then increased at 1/150,000. Differently, degraded forests and fallows decreased from 1/50,000 to 1/75,000, then increased at 1/100,000 and decreased again at 1/150,000. Plantations kept increasing while forests actually only changed very slightly. The areas of the barren lands kept decreasing. We could not therefore associate a general pattern in the variation per land use type.

**Table 2: Areas (by Land Use Types) of Original and Result Map at Each Scale in Ha**

<table>
<thead>
<tr>
<th></th>
<th>Scale 1/50,000 Before</th>
<th>Scale 1/50,000 After</th>
<th>Scale 1/75,000 Before</th>
<th>Scale 1/75,000 After</th>
<th>Scale 1/100,000 Before</th>
<th>Scale 1/100,000 After</th>
<th>Scale 1/150,000 Before</th>
<th>Scale 1/150,000 After</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest</td>
<td>142.52</td>
<td>142.43</td>
<td>142.30</td>
<td>142.14</td>
<td>142.46</td>
<td>141.79</td>
<td>143.16</td>
<td>143.67</td>
</tr>
<tr>
<td>Degraded Forest</td>
<td>104.19</td>
<td>102.61</td>
<td>99.65</td>
<td>97.74</td>
<td>99.36</td>
<td>96.88</td>
<td>91.47</td>
<td>94.81</td>
</tr>
<tr>
<td>Village</td>
<td>1.62</td>
<td>1.53</td>
<td>1.40</td>
<td>1.32</td>
<td>1.47</td>
<td>1.28</td>
<td>0.81</td>
<td>0.93</td>
</tr>
<tr>
<td>Crop</td>
<td>18.99</td>
<td>18.24</td>
<td>18.04</td>
<td>17.18</td>
<td>17.67</td>
<td>16.54</td>
<td>15.04</td>
<td>15.20</td>
</tr>
<tr>
<td>Fallow</td>
<td>198.27</td>
<td>199.49</td>
<td>203.31</td>
<td>202.78</td>
<td>198.12</td>
<td>200.25</td>
<td>205.96</td>
<td>201.70</td>
</tr>
<tr>
<td>Barren</td>
<td>3.33</td>
<td>2.88</td>
<td>2.79</td>
<td>2.27</td>
<td>2.52</td>
<td>2.10</td>
<td>1.62</td>
<td>1.82</td>
</tr>
<tr>
<td>Plantation</td>
<td>252.27</td>
<td>252.75</td>
<td>252.70</td>
<td>254.39</td>
<td>256.26</td>
<td>257.57</td>
<td>256.69</td>
<td>257.60</td>
</tr>
<tr>
<td>Swamp</td>
<td>60.13</td>
<td>61.10</td>
<td>63.26</td>
<td>65.22</td>
<td>65.25</td>
<td>66.28</td>
<td>68.58</td>
<td>67.06</td>
</tr>
<tr>
<td>Water</td>
<td>424.93</td>
<td>425.22</td>
<td>422.80</td>
<td>423.21</td>
<td>423.14</td>
<td>423.56</td>
<td>422.92</td>
<td>423.66</td>
</tr>
<tr>
<td>Total</td>
<td>1,206.25</td>
<td>1,206.25</td>
<td>1,206.25</td>
<td>1,206.25</td>
<td>1,206.25</td>
<td>1,206.25</td>
<td>1,206.3</td>
<td>1,206.3</td>
</tr>
</tbody>
</table>

The largest variations happened in the barren lands, villages and croplands, which are actually the smaller land use types encountered in the area. Barren lands and villages display considerable variations from their initial areas at every scale, with the highest values appearing when the scale is the smallest.
(1/500,000) in this study. Both also displayed high variations in perimeters denoting that it is possible that the general morphology of the entity has higher effect on the area variations. With their small sizes added to the acute angles, the use of the procedures resulted in reducing them to their minimum area. The area variation proportions are quite misleading in that aspect, because the villages for example seem to have decreased a lot even though the change is actually only a 0.12 ha loss (Fig. 27).

The total modification for barren lands and villages actually never exceeds respectively 3.5 and 1.5 ha. Villages and barren lands have mostly rectangular shapes that generate acute angular corners during the geometric scaling. Rectangular shapes tend to become parallelograms. The other land use or land cover types remained somewhat stable. The total area of the forests did not change much.

Overall, however, area changes affected 2.96 ha, 4.06 ha, 4.89 ha, 5.78 ha respectively of the initial document at 1/50,000, 1/75,000, 1/100,000 and 1/50,000 scales.

![Fig. 27: Area Variation Proportions between Initial and Result Map](image)

The changes are therefore small compared to the total area of 1,206.25 ha at all scales (less than 0.5%). However, they exhibit a strict rise that ends up in almost doubling the area of the lands affected by changes as the scale is coarsened down to 1/150,000.
The challenge that arises then is the problem of the beginning and ending points since the procedure does not operate on them. They create a strict limitation of the method.

5 Conclusion

Readability has always been a major problem in map multi-scaling. Under the chapter of line generalization in computer-assisted cartography, many techniques have been built to deal with that problem by deleting a number of vertices. In fact, which problem between putting a document at different scale and dealing with the same document readability is solved by the deletion of the vertices is not always clear. We departed from the vertices deletion and focused on reducing the line’s complexity.

We devised a method to reduce the complexity of the boundary lines of polygons. The method can be applied to any line map. Details along map feature boundaries result from angles formed by triplets of vertices. When those angles are too acute, computer-generated drawing tends to create clusters of painted pixels that finally clutter the map and reduce its visual quality. Angle filling is almost inevitable when the scale of the map is progressively coarsened, making it one of the biggest challenges in map multi-scaling. Our method enlarges the angles in the satisfactory proportions to maintain an acceptable visual fineness while preserving a maximum consistency with original data. We noted that feature boundaries can change considerably based on the number of angles to treat, but areas, and in smaller proportions the perimeters, seem to stay more stable as the scale is coarsened.

This method is different from existing line generalization procedures. First, unlike generalization techniques, it does not eliminate vertices. Second, geometric changes are progressive at each angle instead of either eliminating a detail when a condition is satisfied or not. Third, the value used to evaluate the condition for geometric modifications is calculated based on the scale, which makes the method less subjective.

We also note that the beginning and ending points are not considered and treated by the method. It is finally those points that keep and even augment the cluttering.
6 References


Chapter 3: Managing Multiple Entities Shared Boundary Control Points in Polygon

Map Multi-scaling

1 Introduction

Polygon map multi-scaling in digital cartography has been the subject of many debates for quite a while. One focus is the deterioration of the map readability as the scale of a map is coarsened (João, 1998). In fact, as the scale becomes smaller, so are the shapes. Consequently a cluttering appears in the form of drawing clusters along and/or between the shapes (Part 1, Chap 2 of this document) reducing the map’s quality. In polygon mapping, map quality problems can be generally separated into two groups, the first encountered at the level of the individual shapes and the second at the level of the entire map.

At the level of the shapes, the problem is about the configuration, the data model and the size. Regarding the size, the smaller the spatial entity, the harder it is to represent it. Therefore, to resolve the issue the tendency is to eliminate small size entities in favor of larger ones. For the configuration, the issues are usually about the details that appear in the form of bends, contortions or indentations along the boundaries of the polygons. Those details can create visual confusion and become dark spots in the map. The shape itself can be very complicated especially when the polygon has donut hole. As the scale decreases, the behavior of the boundary line can be rather unpredictable.

Shape level issues are probably the ones that have attracted most attention (Li, 2007). The number of algorithms and diverse strategies already constructed to generalize shape by smoothing the boundaries, reducing the number of details along the boundaries or the features size, or splitting the feature or simply changing the data model, is long and continues to increase.

Map level issues first result from the shape level problems since the overall quality of the map depends a good amount on how the spatial entities are represented individually. However, map level difficulties also involve the density and their spatial distribution of the shapes. The number of entities to represent sometimes becomes the bottleneck of the map’s quality. For example, in land use mapping, the higher the number of land use and land cover types, the higher the number of entities to represent. That
situation often forces the use of different reclassification strategies and can result in related topological questions, connectivity, contiguity and even spatial relationship concerns. The spatial distribution is related to the number of features. Often the solution to solving map level difficulties has involved many strategies such as shape integration, resampling, deletion and reclassification. Many of those techniques, if not all, have been gathered under the more generic topic of map generalization (McMaster, 1987).

The separation between map level and shape level does not mean that there is no intermediate one. There are aspects that pertain to both levels and by which, shape level issues affect the overall map quality. One of such aspects is the object of this study.

This study focuses on the location of vertices that are generally not modified by algorithms operating at shape level and that are much irrelevant at map level, but that have a strong repercussion on the map readability; we identified them as the multiple-entities-shared control point’s locations. For example, in many algorithms of point deletion along a line, the starting point and the ending point are exempted in the calculations. If the boundary of a polygon could be divided into sections limited by points considered the starting and the ending point of those sections, then when applying the algorithm of point deletion, for example, of Visvalingam and Wyatt (1993), each of those points will remain invariant. Whatever the scale, those vertices used as control points escape from the generalization.

Defining starting and ending points is probably a technical problem since any operation acting upon a line needs to begin somewhere, but there is also another important reason. In fact, modifying them can produce side effects, requiring additional modification of all the entities sharing the location, and the result of the chain of modifications may not always be the desired one. The connectivity and contiguity between the features and the entire map topology can change (Han et al., 2004). Dealing with such complications can be very difficult and is actually almost another line of research.

Nevertheless, we noted that the location of those points does not have the same level of fixity in space. Such level depends on the type of phenomenon under study. In the case of a map of a network, - for example, a water distribution system - modifying the location of those points can create a false map with dramatic consequences since often those points identify specific entities such [water] poles.
However, in land use mapping there can be some flexibility, because often the land cover plots have dynamic boundaries. Forest boundaries can change according to seasons while rivers banks can change even overnight. Depending therefore on the type of map, and as long as data reliability and integrity are maintained in controllable proportions some options may be taken, since unfortunately, as the scale is reduced, the number of those reference points staying invariable becomes a major cause that reduces the map’s readability. Dealing with those points is therefore crucial in order to improve the map’s usefulness.

Indeed, it may certainly not be wise to delete those control points. However, a careful management of their location to improve the map readability becomes necessary as the scale is reduced. The goal of this study is to present a way to deal with them with the hope that more attention will paid to them in the overall debate about digital cartography and map multi-scaling.

The rest of this paper is organized as follows: in the first part, we will present our demarche to deal with control points. In the second part, we will present the cartographic result achieved when we applied the technique and finally, we will discuss our results.

2 Method

2.1 Principle

The method is an extension of the angle-based shape adjustment method (Part 1 Chap. 2). At each control point, features touch each other and create angles. Cluttering appears when such angles are small and the plotting units coalesce into clusters. We will first enlarge the angles in the limit imposed by the value of the plotting unit, and then adjust the neighboring features accordingly (Fig. 28).

![Fig. 28: Base Principle of Angle Modification-Based Control Point Location Adjustment](image-url)
In the angle-based shape adjustment method, point B is progressively moved along the bisector (B,bz) until distance \([e_1,e_2]\) is equal to or longer than the real world distance corresponding to three mapping or plotting units. That minimum distance ensures that mapping units on the representation will not coalesce. Initially, two polygon features \(F_1\) and \(F_2\) share control point B. Cluttering will appear first on the side of feature \(F_1\) because the angle is smaller. We use the angle-based shape adjustment method (b) to move feature \(F_1\)’s point B to \(b_1\) (c). Then we adjust feature \(F_2\) to maintain consistency (d).

Segment \([B,b_1]\) is in fact the portion of the initial angle ABC’s bisector passing through points B and \(b_1\). Adjustment consists in moving point \(e_2\) to \(b_1\). The move results in the modification of the four angles \(A_b_1B, A_b_1C, C_b_1B\) and \(b_1BD\). Cluttering cannot normally happen because each angle becomes large enough to prevent the clustering of plotting units at their respective angle or control points.

Fixing one case can result in the adjustment of another case. Therefore, to ensure the least distortion possible at each control point, we calculate and sort the values (distance \([e_1,e_2]\)) for the angles of the feature in ascending order. The procedure starts with the smallest angle to the largest one, recalculates angles after each modification and re-sorts the result. The operation continues only if there is an angle that requires treatment. For example, in Fig. 28, after correcting for feature \(F_1\) and adjusting for feature \(F_2\), there is no need to continue the procedure on feature \(F_2\). The iteration therefore stops.

A set of subroutines were developed in Visual Basic to calculate the points’ coordinates following the procedure presented in Fig. 28 and the results were plotted in ESRI’s ArcMap. The vertices located on the boundary of the test-zone were excluded in order to preserve the rectangular shape at every scale.

2.2 Data

We classified a Landsat TM image from 1986 by maximum of likelihood and distinguished 11 land use or land cover types for a total area of 5,965.78 ha. We converted the resulting raster into a vector map of 1930 initial polygons that we used as experimental map. The current operation does not aim at deleting features, so the total area and number of polygons cannot be subject to change.
Every map can be used, but in this exercise, we applied a scaling procedure discussed in chapter one on this document to the original map before dealing with control points. The XY coordinates of the features’ vertices were exported into a Microsoft-Access Database table where duplicated and useless vertices were eliminated, as well as scale-based redundant vertices. Scale-based redundant vertices are vertices that have different locations in the real world, but that have the same coordinates in device units. We have observed that there is no change in the features’ shape until 1/63,000. Consequently, we start the exercise with the initial scale of 1/75,000.

The test zone covers the south-west corner of the protected forest of Yapo in southern Côte d’Ivoire (Fig. 29) and its deforested vicinities.

Fig. 29: Test-Zone Location Map

The region exhibits a high number of small patches of forest and degraded forest inside a large area made of wide range of land cover types. Agriculture exists in small parcels and fallows of different ages often invaded by *Chromolaena odorata* (L. King & H. Robinson). Intense cultivation has created eroded and barren sectors and other lands covered by diverse species of grass. Cash crop agriculture also exists in plantations of banana and palm oil trees. The protected forest was still well protected at the time of the satellite image’s creation and it helped in contrasting the deforested vicinities.
3 Results

3.1 Connectivity and Contiguity Modifications

The resulting map document exhibits different changes at the shared locations. We observed four main types of changes that we present in the next sections.

1) Isolation

When a feature has only one vertex at the control point, enlarging the angle by moving the shared location vertex can detach the feature from the others (Fig. 30). The feature is consequently secluded. Because of the isolation, the shared location can lose its rank as a control location regardless of the number polygons initially having a vertex at that location.

![Isolation](image)

Fig. 30: Isolation

This example also shows that there is always a feature that has two vertices at that location, and that feature actually fills the space after the seclusion or the loss of connectivity.

2) Splitting

The initial feature is divided into individualized parts (Fig. 31). This situation happens mostly when the original feature has a pair of vertices at the same control location squeezing the boundary of another feature. This situation actually appears very rarely in our study area, and the mechanism looks rather complicated. It almost needs to two pairs of vertices with same coordinates, but belonging each to a different feature. Splitting is somewhat another type of isolation that constrain part of the same to separate
from one another. The surrounding feature fills the gap created. We noted that if the method is applied first to the surrounding feature then the surrounded feature is enlarged because of the concurrent displacement of the control points to maintain continuity and topology.

Fig. 31: Splitting

The parts resulting from the split can be treated as separate entities or grouped as a multi-parts entity. In our exercise, we treated them rather as separate entities.

3) Shrinking

The shrinking is the basic behavior in all of the cases since the technique moves the vertex at the shared location inward to make the angle larger for each feature. It appears more evident in situations in which the angles on opposite sides of the control location are small and need to be corrected (Fig. 32).

Fig. 32: Shrinking

Almost every situation entails the shrinking of a feature. In Fig. 32, features $f_1$ and $f_2$ shrink because of the displacement of the vertex at the shared location. The shrinking happens for the feature subject to the inward pixel displacement.
4) Closing-up

It happens that parts of the boundary lines of one of those adjacent features become irrelevant as the result of the shrinking, splitting or isolation of other features (Fig. 33).

![Fig. 33: Closing-Up](image)

At scale 1/100,000, the shrinking causes the boundaries of feature (f) to start joining. Segments of that boundary having feature f on both sides become irrelevant and are therefore removed. Feature (f) thus closes up around the others that are then isolated inside (Fig. 33-c). The closing-up can happen at all scales and depends mostly on the spatial configuration of the polygons and the angles at the shared location.

Different situations result therefore from the manipulation of the vertices at the shared locations. Vertices at the shared locations are manipulated individually, and adjusting of the adjacent shapes is the principal cause of the map modification. The minimum change has been observed in the case of the isolation, which actually involves only two polygons. From these specific cases, it appears clearly that the contiguity and connectivity between the features can change a lot and have repercussions at both feature and map levels. However, the cluttering mostly hides such connectivity and makes them hard to distinguish in the map when not treated. Their clearance is therefore useful.
3.2 Map Documents

We contrast the scales of 1/100,000 and 1/200,000. The original map was at the scale of 1/75,000, and therefore the scale 1/200,000 is approximately 3 times smaller (Fig. 34).

<table>
<thead>
<tr>
<th>Scale: 1/100,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>The map still looks clear. There are very few darker spots randomly distributed across the map, but overall, the document remains easily readable without any enhancement. Each polygon can be distinguished based only on its boundary lines. In fact, at each of those points, darker areas are made by very small polygons filling. Some of such polygons are clearly individualized. Some of those polygons can be seen in the Northeast corner as well as in the Southwest corners of the map.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Scale: 1/200,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>The number of dark points increases and is obvious in the map. The dark points and sectors are mostly entire features being filled–up by pixels. As a result, isolated polygons appear like dots. The density of the features limits the usefulness of the map even though the method reduces the clustering at the shared location point.</td>
</tr>
</tbody>
</table>

Fig. 34: Comparing Map Documents at 1/100,000 and 1/200,000
At the scale of 1/200,000, the density of the feature creates most dark points and sectors in the map. The size of the polygons becomes smaller and their aggregation in specific areas is the major cause of the cluttering. We can still even distinguish shared location vertices. No cluttering is observable at those locations when the features present are not too small (Fig. 35). The dark spot is the result of the agglomeration of 15 polygons representing different land use types covering barely 13 ha of land.

![Fig. 35: Feature Density-Based Cluttering](image)

Similar to that case, the other regions appearing in dark are made of high numbers of polygons in reduced spaces. At the scale of 1/200,000, cluttering is not a boundary issue but feature density issue. Boundaries also tend to appear thicker because of the number of small features that reduce to dots along them.

In total, application of the method greatly improves the map by reducing the aggregation of drawing units around the shared-points locations. However, the density of features limits its effectiveness. The density of features creates another type of filling effect that happens more as polygon interior painting than as boundary cluttering due to indentations or bends. It is not the number of details along the boundary lines or the value of the angle at the shared location vertices that are the issue. Even at 1/150,000, the map document’s readability was affected to the point where the map could be rejected as unreadable or too cluttered due to the aggregation of entire shapes.
### 3.3 Area Variations

We make comparisons between initial and result map at each scale (Table 3). Areas are in ha. They did not vary a lot. The highest variations are observed at scale 1/200,000 on only 4.95 ha shared mostly between the forest, barren lands and villages. One can see land use types that have mostly small angles contact with the others spatial entities by their constant area decrease, such as the barren lands and those who were losing from such small angles contact such as the bamboo, which in turn was rather enlarged by the procedure.

The small angle variation tells that in fact, the cluttering that affects the readability of the map could be reduced without a major loss of information. The angular sector that is filled when a procedure such this one is not applied, may not therefore be that large.

<table>
<thead>
<tr>
<th>Scale 1/75,000</th>
<th>Scale 1/100,000</th>
<th>Scale 1/150,000</th>
<th>Scale 1/200,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before After Diff</td>
<td>Before After Diff</td>
<td>Before After Diff</td>
<td>Before After Diff</td>
</tr>
<tr>
<td>Forest</td>
<td>1,576.22 1,575.92 -0.30</td>
<td>1,576.06 1,576.17 0.11</td>
<td>1,572.68 1,572.23 -0.45</td>
</tr>
<tr>
<td>Degraded forest</td>
<td>1,464.17 1,464.91 0.74</td>
<td>1,468.57 1,468.50 -0.07</td>
<td>1,488.09 1,489.34 1.25</td>
</tr>
<tr>
<td>Shrub</td>
<td>217.58 217.87 0.29</td>
<td>214.84 214.83 -0.01</td>
<td>211.58 210.96 -0.62</td>
</tr>
<tr>
<td>Crop</td>
<td>346.73 346.73 0</td>
<td>337.47 339.25 1.78</td>
<td>322.19 321.68 -0.51</td>
</tr>
<tr>
<td>Fallow</td>
<td>595.19 594.46 -0.73</td>
<td>592.82 592.91 0.09</td>
<td>594.25 594.89 0.64</td>
</tr>
<tr>
<td>Village</td>
<td>102.17 102.52 0.35</td>
<td>102.53 102.65 0.12</td>
<td>99.01 99.20 0.19</td>
</tr>
<tr>
<td>Grass</td>
<td>1,288.59 1,288.43 -0.16</td>
<td>1,298.14 1,298.63 0.49</td>
<td>1,317.44 1,317.92 0.48</td>
</tr>
<tr>
<td>Barren</td>
<td>85.15 85.08 -0.07</td>
<td>84.76 82.97 -1.79</td>
<td>77.40 77.04 -0.36</td>
</tr>
<tr>
<td>Plantation</td>
<td>211.27 211.04 -0.23</td>
<td>211.76 211.71 0.05</td>
<td>205.99 205.05 -0.94</td>
</tr>
<tr>
<td>Bamboo</td>
<td>74.27 74.38 0.11</td>
<td>74.16 74.16 0.00</td>
<td>73.23 73.47 0.24</td>
</tr>
<tr>
<td>Water</td>
<td>4.44 4.44 0</td>
<td>4.67 4.07 -0.67</td>
<td>3.92 4 0.08</td>
</tr>
<tr>
<td>Total</td>
<td>5,965.78 5,965.78 1.49</td>
<td>5,965.78 5,965.78 -2.59</td>
<td>5,965.78 5,965.78 2.88</td>
</tr>
</tbody>
</table>

Table 3: Area Variations across Scales

In addition, at larger scales, the shared location vertices need to be moved less. We observed that the variations were also related to the number of points shared between each polygon and its adjacent features, even though it cannot be a rule. If the number of contacts increases the chance to have many smaller angles, in fact, it does not always create the necessity to operate on all the angles.
The operation actually is a treatment of reduced angles. The territories covered by the angular sectors are therefore usually small and the procedure minimizes at the optimum level, the vertices’ displacement. In fact, similar to vertices between control points, at each scale the threshold value of three pixels or drawing units reduces the territory covered, which become mainly a function of the distance between the shared location point and the closest vertex; the shorter the distance, the smaller the area.

3.4 Perimeters Variations

Different from the surface areas, perimeters change across scales. The maximum perimeter variation is 6.37 % and it happens in the barren lands at 1/250,000. Conversely, water bodies’ perimeters did not change at the initial scale; when they did change at the other scales, the perimeter dropped due to their initial profile. There are only three of them, they are rather close to circular and their boundary lines connect with the other feature boundaries at rather large angles (Fig. 36). In that case, no modification was necessary which resulted in the absence of change at 1/75,000. The area table also shows that the area of bodies of water did not change at all.

Fig. 36: Shape of Bodies of Water (a) and Sections of Barren Lands (b)

Fig. 36 shows that a number of segments are at 90° angle while others are less than 0.7 radians (in the case of the bodies of water). Conversely, elongated features such as barren lands were more subjective to changes, since as their contact with other features increases, it is more probable to encounter situations that require angle modifications. Those barren lands consist mostly of roads and power lines cutting
straight through croplands, fallow lands and degraded forests, which are land use types of rather irregular shapes. In addition, due to image classification constraints and limitations, they are very discontinuous and in multiple pieces which multiplies the number of angles. The barren lands display a set of angles that need to have their vertices displaced (see arrows of Fig. 36).

Despite the high number of grasslands, crops and fallow plots, we do not observe such big variations. The number of polygons may not be a variable influencing the amount of change in the perimeters. The whole point is about the value of the angle at the shared location vertex.

At the initial scale, the perimeters change little and the maximum is also in barren lands which with the bamboo, comprised the only land cover types whose perimeters change increasingly as the scale is coarsened (Fig. 37).

![Fig. 37: Perimeter Variations Across Scales](image)

At 1/150,000, variations soar and stay high through scales 1/200,000. It is only in the case of the forests that variations at 1/150,000 are higher than at the scale of 1/200,000. Forests are almost surrounded by degraded forests, and therefore the majority of boundaries’ irregularities have been treated as vertices, not as control points at the shared location. This aspect actually illustrates why the number contiguous entities cannot explain the variation in perimeters. For example, the largest forest polygon has a perimeter of about 33,851.58 m but we counted only 37 control points with nine to be displaced, while
for a degraded forest with a 4,400 m long perimeter there are 27 control points amongst which 19 needed to be displaced. Only the actual number of shared location vertices to be displaced explains the changes that happen to the perimeters and the areas of the features.

There is also a general tendency for the perimeter variations to drop at the scale of 1/250,000. We speculated that there might be an effect due to the straightening of the lines due to the angle-based shape adjustment. Indeed, as the shape is straightened, and as the control points are being adjusted from one scale to another, there is a change to end up in an optimum situation in which only a few of those control points will need displacement. Nevertheless, that can be a pure assumption that still needs to be studied.

4 Conclusion

Points at locations shared by many entities are often overlooked by methods and algorithms used to create readable maps at coarse scales. Almost all the procedures for map scaling exclude the beginning and ending points of line. However, the angles such points define with their neighboring vertices often create clusters and dark spots that reduce the map’s visual quality. There is therefore a need to find some techniques to deal with them properly. In this study, we introduced and discussed one of such possible techniques. The idea of manipulating such vertices is quite new and so is the technique we are introducing by this research. The method we present here is an extension of the angle-based shape modification approach. It moves the vertex at the angle along the bisector of the same angle out of the cluttering sector and adjusts consequently the adjacent segments. The result we observed showed that the technique effectively reduces cluttering and improves of the map’s visual quality without major change in the areas of the features.
References


Part 1: Geometric modification for map multi-scaling: Ending Remarks

There is a difference between the scale at which data is collected and the scale at which such data is graphically represented. Appropriate representation requires that both are the same. The number of vertices in a shape does not necessarily depend on the scale of the map. When it does, then 1) such relationship can be calculated and 2), it may entail a change of geometry type.

The conversion from real world coordinates to device coordinates creates vertices of same device coordinates and determines thus which vertex is not useful for the representation. A step to filter out such duplicated vertices is necessary. The additional vertices removal proposed by current algorithms for point deletion is not necessary for map multi-scaling. Proper map scaling requires that such operation be repeated every time the scale of data is changed.

Map cluttering is caused by the distribution of the vertices on the map and that can be seen and solved at two levels:

1) The level of each vertex located between the beginning and the ending points of a line: by reducing the complexity of the shapes through an enlargement of the angle at each such vertices.

2) The level of each vertex positioned at a location shared by vertices of more than two shapes: by successively enlarging the angle at each vertex and adjusting the adjacent shapes accordingly.

This part therefore focused on the geometry of each shape. We introduced three new approaches to put each shape at another scale and clean the resulting cluttering without eliminating any vertices. We remark that if a change in the geometry type occurs, then additional steps become necessary to avoid the loss of such information.
PART 2: ACTIVE DATABASE FOR MAP MULTI-SCALING IN GIS

The first part of this research showed that during the conversion of the real world coordinates into device coordinates, an entity can become represented by a set of vertices with same device coordinates and thus by one point on the map. In such a case, its visibility depends on the map-reader’s visual acuity. Because the multiplication of such cases clutters the map, a common attitude is to remove them from the map. Because such procedures often reduce data accuracy, a solution is to integrate such an entity to an adjacent one. However, a collateral effect of such integration is the need to integrate the attribute values accordingly.

In this part therefore, we examine first how attribute values can be integrated. Second we investigate how features can be integrated along with the conditions under which such integrations can be done.

One way to integrate all these mechanisms efficiently is to construct an active database system. In such systems, in the event that a new scale value is set, a number of routines can be set to run and perform specific tasks. We are introducing an event-condition-action based technique to integrate the cartographic entities.
Chapter 4: Attribute Value Integration in GIS

1 Introduction

Spatial information often has two sides: one related to the shape and represented with geometric features, and one that is non-geometric and stored as an attribute describing some aspect of the spatial entity. During the last decades, many debates have focused on the integration of the geometric aspects, especially its relationship with the coarsening of the cartographic scale. A number of debates on that subject have been condensed under the topics of map and data multi-scaling, multiple representation of the same object in Geographic Information Sciences and systems and map generalization.

Conversely, non-geometric attributes have gained less attention. In the pool of scholarly and research documents about data and map multi-scaling, there is a tendency to combine geometries and eliminate part of the attribute to keep what is common or essential about the entities, even though both spatial and non-spatial facets are still considered related (Mustière & van Smaalen, 2007).

Thus, those techniques are made of a dual simplification that reduces the amount of information provided by the map. Certainly, it makes sense to manipulate the graphics since they can clutter the map but where does the need to simplify the non-geometric attribute values come from?

We note that a map document is made of different elements (Tyner, 2010) which together work to expose the message the map conveys. Those elements can be manipulated independently whatever the scale and some of them do not necessarily need to be changed according to scale. Amongst those elements is the legend of the map. This study seeks therefore to keep the legend manageable at every scale without simplifying the attribute values. It proposes to avoid information loss through geometric simplification by associating and mapping the attributes to reveal the spatial entities’ presence and/or importance as the scale is coarsened. The technique groups entities into larger structures and then maps the composition of each structure through a mechanism of layered information and a scale-invariant legend. In each structure, the component entities are differentiated and exposed by the symbology.

In the next sections, we present a short review of the techniques for attribute value manipulation and then we expose our method and show its use with a map.
2 Attribute Value Manipulation and Modification: A Short Review

Attribute value manipulation is not new and it is usually done for a variety of reasons, even though when representing spatial data at different scales, it almost becomes a necessity. McMaster and Shea (1992) list two operations aimed at transforming the attributes’ values to meet the requirement imposed by geometric modifications: classification and symbolization (Robinson et al., 1984), but other techniques exist. In the next paragraphs, we enumerate some of them in addition to those just mentioned.

a) Classification: The classification operation consists in agglomerating data values (Dent, 1999) into groups sharing identical or similar attributes. It can also be a matter of closeness based on a chosen or given scale of measurement. There is a wide range of classification methods (quantitative and qualitative, typological or ordinal) and often classification creates generic classes that can have an internal variance. Probably one of the biggest challenges when using this technique is how to set the bounds of the classes. Thus, the validation of a class often requires additional criteria since the level of similarity needs to be researched. According to McMaster and Shea (1992), the classification operation is necessary because of the impossibility of mapping individual values, especially numerical values.

b) Definition: Nyergues (1991) mentions that aggregation - an abstraction - can necessitate a new definition because it can be synergetic. The meaning can rise from the combination of the meanings of the elements. Ruas (2000) has given examples of such “compound objects.” The view seems close to the concept of holism [the entirety is more than the mere addition of the parts] (Antrop, 2006) and to the concept of emergence denoting that the whole is greater than the sum or grouping of the elements. The resulting meaning can be different from the definition of each of the constituents used to create the structure, which is in fact a totality. An archipelago (a set of lands separated with water bodies), a wooden savannah (set of trees or groups of trees separated with grasslands) or an oil refinery (an industrial plant made of various installations and aiming at purifying crude oil) can be seen as examples of that view.
c) Elimination: Nyergues (1991) points out an operation of attribute elimination, which proceeds also from the classification abstraction and that, can occur when the attribute is no longer needed. For example, annual crops and perennial crops can be aggregated as crops. The difference between perennial and annual may be in fact little if the annual crops are practiced in continuous cropping, in which case the permanency in space is the same. Leaving out the temporal qualifier, to some degree, changes little in the understanding. Elimination as an abstraction type looks very close to the categorical generalization (McMaster and Shea, 1992) and to the class-based generalization (Mustière and van Smaalen, 2007). Many map generalization studies and methods have given preference to the attribute value elimination.

d) Numerical and statistical calculations: Often, data is integrated for simplification, clarity and readability. In raster-based mapping, attributes can be changed using a variety of filters, which can be pixel-based or cell-based. If the target map is going to have a cell-based structure then it is possible to recalculate numeric attribute values using various statistical operations. McMaster and Shea (1992) distinguish between numerical generalization and numerical categorization. In addition, some of the techniques used to recalculate the features’ attribute values include:

1) Statistical operators or indices such as the arithmetic average or the mode.

2) Simulations: mostly used for grid-based or raster data, simulations extract semi-variance models and then use them to estimate values (Wang et al., 2004).

3) Re-sampling: also usually used for grid-based or raster data, and it often consists of choosing or calculating a new value that represents a set of other values based on a statistical reasoning. Re-sampling techniques are various. An example of value choosing is the choice made to select one pixel every nth pixel from a raster image or grid data.

e) Propagation: It happens that during a study that requires conversion from one data format to another, a decision is made to extend an attribute to some space. A common case is the choice to keep a given value for practical reasons. For example, in a study to show how the processes that explain the
diversity of fauna at a regional level influence the diversity of fauna at a local level in the forest of KwaZulu-Natal, Lawes et al. (2000) chose to give priority to forests when converting their vector map into a raster one. They decided that every cell covering a forest fragment and any other type of land use or land cover type, would be directly classified as forest to ensure that all forested lands were taken into account in the resulting map. The attribute forest is thus extended and propagated to the entire cell on a presence-absence basis.

f) Components enumeration: This way consists in accumulating the values using various association techniques. It can appear as hyphenation like in “Oak-Hickory-Southern Pine” (Barnes et al., 1998) or using a slash as in “Cropland/Mosaic Vegetation” (Friedl et al., 2002); Roman-Cuesta et al. (2011) use the addition symbol as in “Oak + Deciduous Forest.” Another style is the type “Savannah and Dry Open Forest” (Dupont et al., 2000). Association uses sometimes a comma, prepositions such as “or,” “with” (Robinson et al., 1995) and expressions like “-dominated” (Jollineau et al., 2008). The meaning of the linking expression, mark or indicator is not always obvious and needs to be evaluated, often based on the map content and the entities or entity types put into relationship and the title of the document. The same sign can have different interpretations in the manipulation mechanism. Apparently, there is no specific standard guiding such associations or pertaining to the choice of the linking expression, sign or symbol. Often, the order has no importance, and when it does, it is mentioned through a word like “dominated” or through an idea of the spatial distribution.

g) Process-based designation: Sometimes the process that affects the entities creates spatial associations. In forestry and in landscape architecture, several patterns have been schematized. For example, Forman (1995) has described different forest distribution patterns, each of them having a spatial meaning: forest perforation, dissection and fragmentation, which are processes that affect a forested area and create specific spatial signatures. In these cases, the focus is given to the fact that forest patches have become separated with non-forested lands. The agent that created such separation may not even be
known. In the same map, “forests” can be distinguished from “fragmented forests” and “primary forest fragments” can be separated from “secondary forest fragments.” Forest fragments can be regrouped as degraded forest. The spatial signature may be tightly linked to the dynamic that produced it. This technique denotes knowledge of the pre-existing conditions of the entity and therefore seems to fit better in situations in which the history of the entity or space under analysis is known. Process-based designation often gives an idea of the dynamic that the space has gone through.

h) Meaning switch: This happens when in order to associate two or more entities, a different understanding is used such as the function or the role of the entity. The technique, even though often used, is not always obvious, and it relates to the example of the harbor made of docks and wharfs. Docks are buildings designed for a particular function. Similarly, a wharf is a type of bridge but made to relate a land to a ship. The notions of building and bridge have clear meanings. A dock and a wharf are respectively a building and a bridge playing roles so that together in one place, they further allow defining a harbor. What is important is not the nature of the construction, but the role it plays where it is located.

i) Symbolization: The case of symbolization is not completely sorted yet, even though many authors have listed it as an attribute transformation technique. According to Tyner (2010), there was/is a disagreement on whether or not symbolization is an attribute manipulation phase or technique. Symbolization consists in assigning a visual mark or code to the graphics to make the map features. It is often based on or combined with a pre-existing classification which can be nominal, ordinal, interval, ratio-based or other indices-based, and that it uses as background information. Nevertheless, whatever the representation, an adequate symbolization is required to (graphically) show the information.

In summary, attribute values manipulation has a high importance in cartography, and different techniques exist, driven by a variety of motivations. What determines the use of one technique is hard to predict and the case of symbolization is still unsettled.
3 Methodology

3.1 Structure Recognition

Generally, three elements are used for structure recognition: identification of objects, identification of the spatial relationships between objects and measure of relative importance (Brassel & Weibel, 1988). Objects of this study are the land use plots delineated from the supervised classification of a Landsat ETM+ image of 2002. They are agglomerated into new formations that we call structure. Data assumed that spatial relationships exist between entities by their location and contiguity, especially when they share boundaries or are located one within another. The relative importance was calculated within structure (Dent, 1999) by the proportions of the areas and the number of entity types.

3.2 Attribute Value Manipulation Strategy

Phase 1: Data Collection

For this study, when an entity became too small to represent due to the cartographic scale, such entity was integrated into a contiguous one based on the nature of the entity types; every time two entities were aggregated, their land use types, ID number and areas were concomitantly collected and stored in a database table.

Phase 2: Data Treatment, Classification and Analysis

Attribute value manipulation *senso-strictu* starts at this phase. Data was loaded into a Microsoft Access database fitted with Visual Basic procedures to calculate the areas and their proportions. For each aggregation, the different entities are grouped by type for which we calculate the area proportions.

Phase 3: Structure Characterization

The entity of higher area proportion has priority in the characterization of the structures, which are depicted primarily with the components that make at least 75% of their area. The choice can be different and is mainly subject to the number of land use types that together reach that proportion.
Phase 4: Legend

For the legend, we use the components enumeration strategy. The symbology is based on a one-entity-multiple-attributes strategy to enumerate the components that comprise each structure (Fig. 38). We treat each entity-type as an information layer in the structure. The presence or absence of each entity type in a polygon is clear. We associate multiple shadings in the same polygon but each information can be mapped separately. Spatial associations are built vertically to maintain the same legend across scales.

![Fig. 38: One-Entity-Multiple-Attributes Legend](image)

3.3 Implementation

Implementation followed the theoretical model synthesized pictured in Fig. 39.

![Fig. 39: Attribute Manipulation Rule Diagram](image)
The calculation follows the steps summarized and diagrammed in Fig. 40.

For each new structure, an individual temporary table was created to calculate the areas and number of entity types and their proportions. The results are stored in a master table linked to the table containing the features’ vertices’ (x, y) coordinates. Both tables are then used in conjunction to create the cartographic representation with the ESRI’s ArcMap.

3.4 The Study Area

The land used for demonstration is located in southern Côte d’Ivoire (Fig. 41). The area is a highly deforested land originally covered by a tropical rain forest. Agriculture and timber harvest have reduced forests to places that are hard to access, such as swamps. Agriculture in the area combines the small slash-and-burn farming and vast industrial palm and rubber tree plantations whose extension is contributing to the eutrophication of a number of wet lands. Most of the land use and land cover patches have an average size of 0.73 ha and 76.01% of the patches are made of degraded forests, shrubs (34.39 %) and crops parcels.
The land is therefore as an amalgamation of different land cover types (Fig. 42). Shrubs are largely made of *Chromolaena odorata* (L. King & H. Robinson). In fact, *Chromolaena odorata* quickly invades every cleared area as soon as the land is no longer maintained, which often makes croplands hard to distinguish from shrubs. Barren lands are small size sand deposits mostly around the central lake.
4 Results

4.1 Dataset Structure after Feature Integration

Features were integrated such that a tracking number (column “Fid_O”) allows retrieving each feature’s original information. In this snapshot (Fig. 43), while the features with tracking number 915 and 916 did not have any other features integrated into them, the features 917 to 920 integrated some. Feature 919 with land use code, 6 (Degraded Forest) is combined with the features with tracking number 2,359 and 1,698 which have the land use codes of 10 (Shrub) and 3 (Forest). The three components together create a new structure. Since we can get their areas (respectively 15,300, 1,800 and 2,700 square meters) from the database, it is possible to make an internal analysis of the new structure.

At the end of the data integration process, therefore, the database effectively contains the information needed to do all necessary data treatment and analysis. Some of the new structures can have a very long list of integrated entities, while others may not even have integrated any. The number of integrated entities seems to depend mostly on the spatial distribution and the shape of the primary entities. More elongated entities are quickly reduced to lines and get lost from the polygon topology.
### 4.2 Proportionality Tables

Table 4 shows the proportions of areas covered by entity types that comprise each structure.

<table>
<thead>
<tr>
<th>Cartographic Scale</th>
<th>Number of Entity Types</th>
<th>Proportion of Area Covered in the Structures (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>75</td>
</tr>
<tr>
<td>1:100,000</td>
<td>1</td>
<td>60.99</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>90.26</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>99.69</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>100</td>
</tr>
<tr>
<td>1:150,000</td>
<td>1</td>
<td>61.79</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>89.95</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>100</td>
</tr>
<tr>
<td>1:200,000</td>
<td>1</td>
<td>52.29</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>83.96</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 4: Sample Cumulative Area Proportion Covered in Each Polygon

An example of how to read Table 4 (gray section in the table) is that at the scale of 1/150,000, characterizing the new structures with the components that occupy 90% of each structure’s area requires the use of four entity types. The reason is that four entity types cover 100% of the area representing 90% of the total area in each structure); however, if the choice is to characterize the same structures with entities that make only 75% of the structures’ area, then actually three entity types are just enough.

The table shows that the higher the threshold, the higher the number of entity types involved in the legend creation. As the scale is lowered, many entities become smaller and need to be integrated to avoid their loss. The number of entities in the map decreases, while conversely the content of the structures increases. Shape or geometry simplification results therefore in the densification of the content of the new structures. That complexity of the map’s content evolves in opposite directions.

Even though there are seven different entity types in the study zone, at the mapping scales we chose, only five entity types in different proportions suffice to map each new structure without
information loss. We will observe a case in which all of the entity types will be found in one structure. Mapping 95% of the area in each structure requires five entity types at all the scales used.

The number of entity types per structure does not seem to increase linearly and a probable reason may be that contiguity does not depend on scale. For example, if a set of entities has already been integrated at the scale of 1/50,000 and there is no additional entity type contiguous to the structure thus created, then the internal number of entity types will not change. The spatial distribution of the entity types governs their number inside each structure. When that number gets to the maximum equivalent to the number of primary entity types, variations stop. A higher variability can therefore be observed at intermediary scales until the number of primary land use or land cover types is reached.

Additionally, at the scale of 1/100,000, the table indicates that representing each polygon by the entity types that comprise 75% of the polygon surface area requires the first four entity types with the higher area proportions. Actually, with the first three major entity types, 99.69% of that surface area is already covered, and a choice can be made to use the smaller number of types. However, it would require five of the entity types to reach 95% or more of the structures’ areas.

At the scale of 1/150,000, the table displays a pattern comparable to that of the scale 1/100,000 especially when less than or equal to 95% of the polygons’ area is considered. The first three major entity types cover 75% of the polygons’ area while the first four major entity types cover 80% of such areas, but five are required to make 95%. The thresholds are almost the same for both scales. The main difference shown at the scale of 1/200,000 is that five major entity types are needed to cover 90%. At higher proportions, the numbers are quite comparable to those of the larger scales.

There is no absolute rule that would link the scale to the number of entity types per structure. In addition, it is not always the case that all the types of land use are needed to portray the structures. Each scale presents a specific case that needs to be dealt with independently.

We note also that as the scale of the map is coarsened, representing each structure with only one entity type may not be recommended because it can be the source of misinterpretations if the area is very heterogeneous. For example, one single entity, even though the largest in our case, does not make 50% of
the structures’ areas. With more entity types mapped, one can get closer to the area proportion threshold. From the scale of 1:100,000, at least three entity types are required to comprise an area proportion more than or around 50% of the area of the structures.

Some cartographic choices also stood out. For example, the features integration process clearly put an exception of water bodies, and as such, we did not have structures that combined water patches and other land use or land cover types. Some combinations also make less sense, such as when a swamp is combined with a nearby forest patch. The result remains thematically a swamp even though both the forest and the swamp will show on the map. In addition, the central large forest also was excluded from the integration process. These observations portray a variety of integration options.

4.3 Symbology

Symbology creation has been very challenging in this study. The symbology is certainly better in a color map since combining proportions and types increases the number of legend casts. The use of colors strengthens the visual quality. At the scale of 1/200,000, the color map is much easier to read than the gray scale. We note that the size - and much more importantly - the shape of the structure had an effect on the application of the symbology. Complex shapes tend to sink the patterned symbology because of the number of boundary lines. Those lines become easy to confuse with the actual legend shadings. Different printouts showed even that the quality depends on the printing device and the file format.

We also noticed that some lines even disappear during the print out. Often in that case, the entity type with higher area proportion tends to stand out more in the structure and in the map. Such situations complicate reverse-engineering calculations. The symbology influences the possibility to recalculate the areas from a printout without involving the initial data. The legend strategy presents therefore the advantage to show in each polygon three levels of information: the different land use or land cover types, the number of types and the proportion of each type. Concomitantly, the legend allows keeping a small and manageable number of legend casts. Recalculating the areas from a printout depends first on the quality of the printing.
Fig. 44: Multi-scaled Maps
Map multi-scaling presents actually many advantages in spatial analysis when it does not delete details, since it reveals the variation of the heterogeneity or complexity of the landscape (Fig. 44). For example, the number of entities per structure is much smaller around the central lake where the most complex areas are swamps. In the northeast, the land use units seem to associate principally to one major entity, which is a shrub. The other entities are quite large enough to escape from being merged into others. The northern part and the southwest parts are more heterogeneous while the northeast side of the areas shows very few changes in the content of the structures.

The dominant type in the structure can change across scales. That aspect translates in the changes in the landscape’s appearance. The type that has the largest area is not always the major one in the structure. Small-sized entities but in large number can still be hard to see in the map even though in term of area, they can be the one occupying the largest proportion of the space of the structure.

An additional problem is the class bounds. Which proportion of the total area is pertinent enough to characterize the whole structure remained rather hard to determine and our choice of 75% is based rather on an idea of an “acceptable” minimum, mostly for demonstration.

Options are conversely numerous. For example, only seven structures in the map have more than four internal components. Such cases open the question as to how pertinent it is to map them, especially when the area such structures cover is less than 1% of the study area. We decided not to map them.

Mapping the components inside the structures offers therefore many advantages and opens more options, cartographic choices and to the capacity to have more control of the amount of information provided by manipulating the importance of the entity types.

5 Conclusion

Representing spatial data at different scales is a challenging operation in which information may be lost. Different solutions have been proposed which are based on information reduction. Most usual practices consist in abandoning part of the attribute value to keep what is considered common, important or pertinent. Alternately, we proposed an approach that is rather cumulative through two mechanisms.
Attribute values are added to one another in the same fashion geometries are. The combination of the shapes results therefore in an association of the attributes. Then each entity member of the compound-structures can be mapped according to its importance within the structure using the same legend at every scale. Entities whose shape is no longer visible are therefore still mentioned on the document through the legend. We have argued that a cartographic document is made with different components that work together to provide specific information. In this study, focus was given to keeping a steady legend to map layers of stacked-up information and maintain data consistency across scales. In each layer, the presence of each component in the structures can be mapped with much ease. However, when the importance inside each structure is involved, the main difficulty we faced was to create a symbology that renders the area proportions without too much confusion.
6 References


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Chapter 5: Active Database for Map Multi-Scaling in GIS

1 Introduction

Designing rules for map integration and multi-scaling is not a new topic in Geographic Information Sciences. As the cartographic scale is reduced, the density of the features clutters the map and creates a problem of readability. The loss of readability impairs the map’s usefulness, since it creates a lack of visual clarity and loss of information. Many studies have therefore designed and proposed a number of techniques to improve the map’s visual quality. Three lines of thought have captured attention: 1) detail elimination along feature frontiers, 2) feature elimination, displacement or merging and 3) feature composition from pre-existing features. The list of approaches is quite long, encompassing line generalization (Douglas & Peucker, 1973; Visvalingam & Whyatt, 1990), rule design (Sester, 1999), ontology (Kulik et al., 2005), database systems (Vangenot, 1998; Rigaux et al., 2002) and abstraction (Timpf, 1999, Mustière et al., 1999).

However, in addition to information loss, difficulties are numerous. Feature elimination can create a need to modify the attribute values. Polygon integration can be done by dissolving a feature into another or by splitting such a feature and distributing its parts into the adjacent entities. Feature re-composition can require changing the data model (McMaster, 1992). These cases are hard to deal with.

Two salient aspects of the techniques proposed are, first, each aims at performing a single operation for a specifically chosen aspect of data processing, and second, they lack flexibility as opposed to manual cartography, which has also shown its limits. Bringing both ways together has been shaping new perspectives, appearing under the chapter of intelligent Geographic Information Systems suggesting that the entire operation of spatial data processing is more than just running routines.

In that line, some automated approaches go further that are more reasoning-based such as rule-based systems (Abdelmoty et al., 1993), deductive databases (Paton et al., 1995), expert systems (Forrest, 1993 & 1999), machine learning (Sester, 1999) and artificial intelligence tools. Those systems support the idea of examining and evaluating different situations in order to make more choices that are meaningful. Despite their great promise, the very few implemented are still rather unknown by the public.
This work goes in the line of a multiple-tasks oriented approach. We argue that map scaling is a process of map creation and therefore multiple-operations-based. We wondered thus more about which routines should be used, in which order such routines should be executed, and how to pass from one to the next. We put together a set of procedures that convert real world coordinates into devices coordinates, deal with the map’s readability and adjust the attribute values using different mechanisms. Those operations are nested and launched by database triggers simulating the choices made by a cartographer at work. In the next sections, we first describe our strategy, and second, present some of the possible results.

2 Method

2.1 Rationale

We first distinguished between “map scale” and “data scale.” The map scale is the scale at which data is visualized. In computer-based mapping, that scale is usually managed through the functions of the zoom-in and zoom-out. The system reads data encrypted in real world coordinates and converts it into device coordinates based on that scale in order to display it. The map scale is the scale at which data is displayed. The “data scale” is the scale at which data has been collected or as encrypted in the database of the automated system. For example, it is common to scan and geo-reference a map document for its use in a computer-based cartography system. In that case, the data scale is the scale of the scanned document.

In aerial-photography-based cartography, when automated zoom-in-out is not involved, usually both scales are the same. In fact, the scale of data in the aerial photographs determines the scale of the map. Multi-scaling first operates at the level of the data scale. A great advantage of manual cartography resides in that flexibility to make decision and chose different geometry types during the cartography.

If information gets lost in the representation for being small, then what is needed is a system that can become aware of data about to be lost, and therefore captures, keeps and manipulates it in some ways and makes it appear at the smaller scale in some given better form.

We thought of map multi-scaling as project-driven, made of a sequence of such decision-making phases requiring actions when specific conditions are satisfied and built two sets of routines one to deal
with geometric issues and the other to calculate suitable attribute values. Each scale modification is seen as an event that triggers procedures in the line of the active database systems (Paton & Diaz, 1999).

Paton (1999) defines an active database as one that is capable of watching and reacting in a timely manner to particular conditions occurring in the database; such a database should have an execution model and a knowledge model that usually uses rules made of an event, a condition and an action. We assimilated the decision to create spatial data at different scales from existing ones to events.

2.2 The Database

We built a Microsoft SQL server database and coupled it to a graphic interface to display the output maps. At times, we also used Microsoft Access and the ESRI’s ArcMap to crosscheck the results.

2.2.1 The Database Schema

The database considers three entities: the spatial reality with geometric and non-geometric attributes, points with their spatial coordinates and lines that are understood as the materialization of spatial entities through a weak entity, the ground profiles (Fig. 45).

![Fig. 45: Relationship between Profile and Entity](image)

The profile is more abstract and can disappear if the scaling generates a shape that is no longer pertinent or the representation is integrated into another. The profile can be modified independently from the attributes of the entity it represents. For example, a profile line can replace a profile polygon. The line has no surface but the database keeps the area value, which can serve as reference to evaluate the changes.
2.2.2 Facts inside the Database

Facts are statements or observations. Often they result from a select query. For example, a select query on the number of distinct vertices can return only one vertex, which is a fact. Facts can be the result of a calculation. A fact can be that the distance between two entities is less than the threshold distance. Four facts are at the basis of all transactions: a change in the data scale, the presence in the database of vertices that have same coordinates, a change in the data model and the creation of a new entity.

2.2.3 Rules Definition

We express the rules in the form of conditions. We distinguished data model-level rules operating at the level of individual representations from map-level rules that operate on the entire map.

Data model rules check for the consistency between the original data model and the new one after the new scale is applied. For example, if all the vertices in a profile have the same map coordinates then the data model can be changed to point and the feature represented by its centroid. If the vertices can be grouped into two classes of same device coordinates then the data model would be changed to a line. The feature will be represented by a line using a representative of each class as beginning and ending point.

Map-level rules examine different situations using a minimum separation distance. For example, we check for features reduced to points to see if all such points fall completely within another feature. In such cases every triplet of points found and falling within the threshold distance was used to create a new entity. The threshold distance used is the equivalent in real world distance of 1.5 device units.

Entities sharing a common boundary segment can be integrated based on land use type affinities. For example, if an entity of type “Barren” is contiguous to a village, a river and a forest then it will be integrated to the village. A table of affinity priorities has been created accordingly. The system works on one feature at a time and decisions are case-based. For each polygon, all contiguous feature types are evaluated and the best-fit is chosen. One limitation of the affinity technique is that if the polygon falls completely within another then there is no much choice than integrating it into that one. We chose the option to integrate always based on the primary types of land use and land cover.
2.2.4 Procedures

There are mainly five entry procedures corresponding to the base modules set up for the cartographic construction steps: recalculate the coordinates and filter them, adjust the shape, correct the position of the control points, recalculate the attribute values and create derived entities. A procedure can involve a set of tasks such calculating distances or selecting coordinates.

The results of the procedures are interpreted as events that can cause triggers to fire depending on the interpretation. A set of triggers were defined and ready to execute when the interpretation of a result is correct. We expect that such method will capture and present more information (Fig. 46).

Fig. 46: Sequence of Operations for Event-Condition-Action Processing

Scale change is the first event that starts the mapping process. If the new scale is different from the one in use then triggers fire to initiate the translation of event results into facts, check the rules and conditions, and initiate the appropriate procedures. Triggers connect procedures, automate the system and play the role of decision-making blocks that authorize the action to take, similar to a manual cartographer checking his work and deciding the way to go at each step of the cartographic design process. The automation stops when geometries and attribute values are calculated. The symbology was manual.
There are two execution phases: map level and feature level. Fig. 47 shows the execution model at map level. Square boxes refer to events and facts, ovals to conditions and hexagons to actions. The event-condition-action was used in different other situations. For example, at feature-level, when an entity is integrated into another, such an event is followed by recalculation of polygon centroid coordinates.

Fig. 47: Active Database Map Level Execution Flow-Chart

* That polygon can be a derived or an initial polygon
2.3 Test Zone

The test-zone is a portion of the National Park of the Marahoué in the Côte d’Ivoire (Fig. 48). The total area is about 5,000 ha with total number 1,274 polygons.

The eastern side of the area shows a concentration of croplands, degraded forests and shrubs of various small sizes. In that area, the itinerant small size annual and slash-and-burn agriculture associated with wild fires generates different plots of land use and land cover that make the area very complex. On the opposite, the western side is comprised with large natural vegetation types. That corner is a section of the deforestation front entering the Park from the Southeast. The interior of the park is rather more homogeneous and less disturbed even though it is still exhibits land cover patches of different sizes.
3 Results

3.1 Derived Data

After converting real world coordinates to device ones based on the scale value, it happens that for some entities, all the vertices in a profile have the same coordinates. In that case, the feature is represented by a single point. We could observe that the device coordinates of that single point are very close and even identical to the device coordinates of the initial polygon’s centroid depending on the shape of the polygon. Because of that situation, some features representative points can be overlapped.

There are also other various complicated cases. For example, the feature can reduce to four or six vertices, but that are contiguous. In that case, the entity looks like a large point or a wide line segment. The number of situations similar to those cases seemed to derive from the variety of shapes of the land use patches. The real difficulty with such situations is that it is hard to shade them with patterns symbology or to combine symbols. Nonetheless, we accepted them without any further treatment and saw that in some cases they tend to create local cluttering. In addition,

In the case where the polygon’s vertices reduced to two distinct points, we output only when the result in that case is a single line segment. Visually, the linear form becomes noticeable when the line is at least three pixels long and does not create an acute angle with a connected segment. If an angle is created, then depending on the value of the angle, the segment can be lost during the de-clustering phase. We could not see -a clear case of a straight reduction to a multiple segments-made line. Interestingly, the proximity between segments sometimes creates connections that give a visual impression of poly-line (Fig. 49).

![Fig. 49: Figures of Segments Connection](image)

(a) (b) (c)
Connections between two segments (Fig. 49-a) are very common, followed by those of three which are quite rare (Fig. 49-b). Sometimes the connections define complex figures (Fig. 49-c). It is therefore possible to get some poly-lines through such connections, which are not calculated but the result of the spatial distribution of the points.

A printed map document will certainly lose the spatial information pertaining to the area of the entities that served to build the lines. However, the presence of the lines on the map is a gain. Their repartition also gives an idea of the entities’ closeness in space.

Fig. 50 displays an example of new polygons. Single polygons exist in great number but often they aggregate into sets of three-vertex polygons to define larger polygons. Those shapes were further merged. The technique actually proved good at summarizing spatial information by creating larger polygons even with ‘donut’ hole while squeezing around the points. The detailed boundary of the new polygon shows that no extra space is really added since only connected points are taken. The boundary line of the polygon goes from one point to the near within-threshold distance point to define well-sized polygons. The new polygon fits appropriately in the initial map and the matrix feature.

We calculated such polygons only for groups of entities that are surrounded by a single other entity based on the idea that such groupings generally express local variations in the surrounding entity and in such a case, it is possible to use the surrounding entity as matrix land cover or land use unit.
The three derived layers (points, segments and polygons) can be analyzed separately demonstrating a strong flexibility of the technique, which opens thus a new analysis strategy, which is manageable at every scale. In our study, we considered a fixed threshold value given by a cartographic unit. However, it is always also possible to try different threshold values, in order to study the level of aggregation at each of them with the capacity to typify entities and calculate their geometric characteristics. At each scale, we could see features that were isolated, those that are close enough to one another to define a line segment, as well as those that could be agglomerated into new polygons.

We did not worry about what the internal structure of the derived polygons would be but simply mapped it to show the composition.

Another aspect is the capacity to maintain the entities’ location on the map through these new constructions. In the case of strict integration, such as for isolated entities merged into others, there is a loss of the precise spatial location. We can only keep the entity as a member of a larger structure and suggest its presence through the manipulation of the legend. However, because the points representing the entities become vertices in the new structures, they give a better suggestion of the location of the entities centroids.

A point that became debatable is the integration based on the primary entity-types. In theory, it is doable and quite straightforward. However, as soon as the result is two different entity types in the structure, a question arises as to which member of the new structure best fits for integrating any new candidate member. For example, when the first entity in the structure is a forest with which a degraded forest has been associated, if the next candidate is a shrub then it fits to associate shrubs and degraded forest. However, such association will not be made because the primary receiver is a forest. Further rules and decisions would be necessary to deal with such cases and the active database system had the potential for adding new rules. Nevertheless, we put a cut at that level to limit the number of options since, after all, no clear standard exists to guide those choices. In addition, the choices we made proved to be pertinent enough with regard to the objective of making an optimum number of entities types appear in each new structure.
3.2 Map Composition

The derived datasets were combined to produce the final map (Fig. 51). The map composition workflow follows the steps described by the knowledge model of the database for map level integrations.

Fig. 51: Map Composition from the Derived Layers

At the scale of 1/100,000, 3,714 polygons from 4,206 were reduced to points, meaning all the vertices of each of these polygons had the same device coordinates; 88.30% of the entities covering
22.61% of the area can no longer be represented as polygon even though technically they are still coded as such. More importantly, 48.22% (747.74 ha) of those patches are forest patches and 22.48% are grass savannah areas. Forest patches covering close to 15% of the area and representing 37.73% of the forest in the area can get lost in the statistics if the patches should be reclassified or simply integrated in other land cover types without accompanied measures.

The high number of small patches can be explained by the fact that the land is ecologically part of the transition zone between forests and savannahs. In addition, the forested area is undergoing a strong cash-crop agriculture-based forest fragmentation. The same arguments also explain the high proportion of small savannah patches. Savannas in those areas are the result of both nature and human actions. The two most important natural vegetation types the ones that can actually lose the most in the statistics.

Technically, we eliminated the points that participate in creating polygons from those used to create lines. That procedure has actually reduced the number of line segments.

Amongst the new points (3,714), 1,854 were retaken into 230 new polygons covering about 412.88 ha when combined with the areas of the initial entities and 461 into 250 new line segments whose corresponding entities cover roughly 41.49 ha (start and ending polygons only). There is an uncertainty in those numbers. The reason is that we are using the entire area of the initial polygons even though after scaling, only a fraction of the original size may be present in the new structures.

The remaining points correspond to isolated entities and they were integrated into the most appropriate contiguous entity to build compound structures. Such integrations do not actually result in a loss of information unless afterward the denomination given to the new structures is not adequate. In total, about 125.91 ha were integrated into other polygons. The process rid the initial map of any points and left only polygons. Visually, these entities are the ones the map-reader will not see or get a better idea of the spatial boundaries and location, even though both properties remain constricted within the limits of the entity that incorporated them.

In the end, the derived data, polygons that stayed invariants or integrated those reduced to points, lines layer from polygons reduced to segments are integrated to create the map at the new scale (Fig. 52).
3.3 Map Documents

Fig. 52: Multi-scaled Maps
At 1/200,000, the scaling by zoom-out looks more confusing with some spatial variation completely unreadable. The scaling method we use tends to concentrate the information in a better way. For example, in the northwest corner and the center of the map, degraded forest patches became almost visible in the zoomed-out picture. The fact that the system could derive new information and add it to the original is an advantage since it strongly reduces the amount of information loss, especially when the map document should be used without its attribute database attached. More information stays visible graphically. The result map documents are therefore of better quality on the three aspects: the readability, the amount and quality of information aspects.

In fact, we noticed that the use of the triggers opens many possibilities since the number of rules and conditions is not limited. We could therefore deal with specific situations, but excluded them from the general processing. Rules definition offer the flexibility to flag, exclude or design specific operations for different parts of the same dataset, and treat them differently. For example, the river in the center of the map was flagged and excluded from integration. Those manipulations can be done at the level of each entity or the entire map, but they can be scale-based. For example, we made the decision to avoid showing the presence of savannas in the central forest patch at the scale of 1/150,000. The sets of conditions and procedures can be manipulated at will, which gives the system a flexibility closer to that of manual cartography.

We note that automating the symbology was rather difficult, since only a visual evaluation could determine whether the visual quality of the map document was acceptable or not. The choice of the symbols turned out completely manual mostly because only a few aspects pertaining to the size of the symbol can be calculated automatically. Besides, even though the legend casts were nicely differentiated often their application to the map did not create an acceptable and readable document. The overall aspect of the document plays a role in the effectiveness of the legend created through the distribution of the entities. The symbol-sets available in the computer-based cartography system we used were not enough, especially when it came to expressing the proportionalities by vertical bands.
Processing time proved to be a major weakness of the entire system. The back-and-forth movements between the routines and searching between the large quantities of data make the processing very slow. In addition, we found that running the system with intermediary checkpoints was very beneficial, which added to the symbology issue shows that at least at this stage of the research, human interaction is still needed.

4 Conclusion

Map multi-scaling has been a major topic in digital cartography for a couple of decades already and the number of techniques proposed show the interest and importance of the subject. Many of the techniques proposed are single algorithm-based. In this study, we present a method that associates different procedures and uses rules to trigger the task that needs to be done on data. The method works on an event-condition-action in the line of the active database systems to calculate the map features every time the value of the scale is changed. We could prevent information lost by capturing data that becomes too small to represent and associate it into compound information that we map at smaller scales without cluttering the map.

The triggering mechanism plays the role of decision-making building block that bridges the facts (data) and actions (procedures). Its purpose is to evaluate the facts created or given, and consequently take action by launching the procedures accordingly designed. Cartography in the context of an active database allows separating spatial information into different levels or layers. It also gives more control over data allowing the manipulation of each level of information independently. Visibility is improved and increased in each layer and kept when the layers are stacked up afterward instead of mapping every piece of information in one overfilled layer. Symbology design and application could not be associated to the automated procedure since we did not have a computer-based mechanism to evaluate the visual aspect of the map document.
References


Part 2: Active Database for Map Multi-Scaling in GIS: Ending Remarks

Many techniques have been proposed for map multi-scaling. Two common characteristics of those techniques are that they are single-task-oriented and detail elimination based. We have showed that actually, map multi-scaling is a multi-tasks operation requiring decision-making phases. The order of succession of the tasks may vary since map making is project-driven. Not all the tasks may therefore be always necessary.

However, because each procedure deals with only one aspect of the problem, using the set of techniques ensures proper data manipulation in order to produce a pertinent and reliable map document. The evaluation phases to decide when to go to a next step cannot be skipped. The need for a mechanism capable to evaluate the state described by data and to react to select a next step in the treatment justifies the use of active database systems. Going from one phase to another happens in the event that the new scale value requires re-convert from real world coordinates to device coordinates. In that case, under the conditions that the conversion creates situations where there is a need for filtering, cleaning or integrating features, additional routines may be necessary to adjust data and its cartographic representation. For every integration, the recalculation of the attribute values is necessary.

At this point therefore, we have a map multi-scaling tool with calculated scale value-based vertices. The system is also capable to not only avoid detailed data deletion or omission, map cluttering but also capable to integrate accordingly the geometries and the attribute values and thus port data across scales with reduced information loss if any. The main cartographic weakness is the difficulty to construct a symbology that efficiently visualizes the results.
PART 3: CASE STUDY: MULTI-SCALING THE PARK OF AZAGNY’S SPATIAL DATA

With this part, we are applying the method built to examine the case of the National Park of Azagny and its vicinities. It is not only another test of our method but also a search to show that with better data, forest management policies could have been better. Dealing with deforestation comes first to collecting and analyzing data about it and making decision based on such data analysis. Data quality is in the background of every activity undertaken to contain and reverse the process of deforestation.

This part of the research first shows that the problem of data accuracy in forest management is not new in Cote d’Ivoire. Before the forest exploitation started, the generalization of local scale data to the entire forested area created a gap between understandings, policies, discourses and ground operations on one hand, and the realm of the terrain on the other hand. As a result, deforestation was fast and unseen until it was too late as we show it in chapter 2.

Currently, regional data is still needed. However, the use of single-task-based generalization procedures found in automated mapping systems eliminates an important part of the spatial information. A wealth of forest that could help design better policies cannot be mapped because lost during the mechanism of detail-deletion-based map multi-scaling. Some people have therefore proposed local scale studies even though local studies were in the past at the origin of many mistakes. In the previous part, we studied and designed a method to data even when reduced to single points across scales. In chapter three, we apply therefore the method to the case of the case of the National Park of Azagny and examine how far policies could have been better if data was created with such cartography system.
Chapter 6: Deforestation in the Côte d’Ivoire: Spatial Data and Forest Mismanagement

1 Introduction

Deforestation in the Côte d’Ivoire has been at center of numerous debates during the last few decades. Deforestation literature presents the country as one of the most compelling cases of environmental disasters in the world. Indeed, Exploitation has depleted much of the country’s forest capital. The matter is taken so seriously that the country has ratified almost all the environmental convention of the United Nations. Reforestation programs, environmental awareness campaigns, environmental assessment protocols and laws, natural resources management policies, sustainable use agencies and fire mitigation agencies have been implemented with the hope of gaining a better control over the country’s natural wealth.

However, a very curious aspect of that deforestation is the strong disagreement on statistical data. Even though the amount of forested lands in the country has drastically decreased (Repetto, 1993; Fairhead & Leach, 1998), the differences in the data used to show it are rather compelling (Fig. 53).

Fig. 53: Area of Tropical Rain Forest in the Côte d’Ivoire from 1900 to 1990 (million ha)
It is almost certain that the variety of sources, scales and format of data, and even probably the methodology used had a large impact on the statistics, especially when they apply to a country that had no specific cartographic standards. What realistic policy can be implemented in such a case?

We went back to investigate the relationship between spatial data and the disastrous deforestation, to see how the whole situation started and what went wrong.

This paper presents a short timeline of the deforestation process and discusses how some aspects related to spatial data drove the forest policies that fueled it.

Different types of documents were used in this examination. The first are various manuscripts and reports from import/export companies operating in the country, and the second includes archives of the ministry of agriculture, in addition to colonial studies manuscripts, monographs and explorer diaries.

Two set of maps were georeferenced and digitized; the first from Chevalier (1912) and the second from Guillaumet & Adjanohoun (1971) to examine the forest coverage; we reclassified the legend of the last map in three classes, forest, forest under agriculture and forest under logging, and then removed the forest under agriculture as non-forest. The country limits and major river shape files created by the ESRI were used to georeference the map documents. Statistical data about productions and surface area are from the Ivoirian National Institute of Statistics’ official agriculture statistics and diverse research on timber and cash crops development in the country. Those documents contain acceptable quantitative data about the country’s crops and timber activities from 1900 to 1985. We examine the country through three periods, before 1893, from 1893 to 1960 and after 1960.

2 Before Colonization

2.1 Timber Trade and Deforestation Existed in Pre-colonial Times

The Côte d’Ivoire became a French colony in 1893. However, before then, a well-established and non-slavery system of trade based on natural resources existed between the people of that region and Europe. In his letters of early 18th century, Bosman (1705) described many plants from the Slave Coast, Gold coast, and Côte d’Ivoire that could be of high value to the European society. At that time, the inland
frontier between those “coasts” was rather fuzzy and things remained quite in that state until around 1912. Bosman was interested mostly in the ivory from the Ivory Coast, but described many “exotic” plants without precise spatial location.

Before the slave trade period, forest resources and wooden products not always labeled as timber product shipped to Europe. Bulliet et al. (2010) report that from 1672 to 1752, 40% of the commercial profit made by the Royal African Company (operating mostly in the Gold Coast and Slave Coast), came from gold, ivory and timber. Dickson (1969) wrote that timber contributed to make port activities less temporary and of more “significant magnitude.” Timber trade from Axim and neighboring ports was so intense that by 1800, it totally cleared the entire area surrounding the port of Axim, with all the trees cut and exported. Exports eventually fell because of the difficulties of harvesting further and transporting trunks to the port.

In 1887, timber exports appeared “back” on export notes (Dumett, 2001) using waterways. The main river used was the Tanoh River, the natural frontier between the Gold Coast and the Ivory Coast (current Côte d’Ivoire), debouching at sea in the Ivory Coast. The same author reports that officials of the Gold Coast and loggers were very active in ensuring that all the timber produced in the Tanoh River basin be transported directly to British-controlled ports instead of to the French trading posts of Assinie or Grand-Bassam in the Ivory Coast.

Timber export to Europe was therefore not new in that area by the time the French settlers were getting their first contacts with the forest. The limits between the Ivory Coast and the Gold Coast were rather hard to distinguish in the hinterland. Besides, the people of that area are of the same ethnic group. Axim timber trade spanned East amongst the people of the pre-colonial Ivory Coast.

Often, only the timber that shipped from the trading posts of the Ivory Coast was mentioned in books. Shipments harvested in the Ivory Coast, but shipped via the Gold Coast, were not mentioned as such. Deforestation around Axim as far back as we could go is the first known disaster regarding this forest that actually spans from Ghana to Sierra Leone. It was with such history that the near colonial era started.
2.2 Fascination with the Ivoirian Forest was based on a Limited and Local Knowledge

Perhaps one could summarize all the impressions about the Ivoirian forest of that time by citing the claim of Chevalier (1909) writing that “The forest of the Côte d’Ivoire is one the most powerful ones in the world.” The author noted with less attention that only half the total area, about 120,000 sq. km, was still in its original virgin rain forest state, but also that the Côte d’Ivoire was at that time, the youngest of the French colonies. Most of it was still to be discovered especially the forest. The author constructed a map that shows the repartition of forested areas from Senegal to Nigeria at 1/3,000,000 is below (Fig. 54).

![Map of forested areas from Senegal to Nigeria](image)

Fig. 54: Limit of the Tropical Rain Forest in West Africa around 1912 (Chevalier, 1912)

The first problem reported by Chevalier was the idea that extracting 300,000 m$^3$ of timber, said to actually represent the total pay load of the 200 ships [of that time] from that forest, would represent only a millionth of the wealth of half of the entire forest. On that ground, political propaganda argued that exploiting the forest for a hundred years would not even modify the landscape (Houdaille, 1920).

In fact, exploitation was concentrated on specific species harvested near the riverbanks and lagoons, which were also used for transport. Consequently, elsewhere everything looked undisturbed.

The second idea grounded on the local fallow-based agriculture system was that everything grows back to the original state with the same composition after cultivation. The vegetation effectively grows back but takes a time that the local people estimated at about 70 years. In addition, that the new composition would be similar to the original one has not always been proven.
A third idea was the claim by Chevalier that before the French settled in the Côte d’Ivoire, the forest had never been exploited for timber and that the first tree trunk sent to Europe from the Côte d’Ivoire shipped around 1880. Probably at that time of the colonial race, it was convenient to present the area as no-man’s-land to avoid competition. Similar claims appear in numerous writings, some even arguing that French navigators were the first to sail to that region as early as 1340 (Villamur & Richaux, 1903). These claims pertained more to a strategy to claim the territory as a colony.

A fourth misconception was about the impact of the local people. No report mentions a trace of exploitation by the local people, leaving the impression that during the centuries before the contacts between Europe and Africa, human activities were inexistent or only reduced to a couple of clearances.

However, the composition of the forest showed a clear impact of agriculture. The forest abounded in rapid growth species such as Bombax, Anthocleita, Funtumia, and Mussanga smithii, capable of growing 75 feet in 7 to 8 years and fill clearances. Many villages have moved around due to exoduses, wars and slave hunters during the previous centuries, the impact of people was deeper than claimed.

Before the period of commercial logging and cash crop development started, the forest was already disturbed and composite. At a time when maps were made by ground observations, it was difficult to get maps showing all the spatial differences. The views provided were confined to accessible lands. The bigger picture could not be captured and was expressed through unfounded general opinions that unfortunately, defined the political and commercial framework in which exploitation started and evolved.

3 The Period after World War I: Colonial Time and the New System of Exploitation

3.1 Europe Needs Timber from its Colonies

The need of timber rose in Europe since the 13th century. It remained a concern during the next centuries (Puyo, 2001), triggering and driving the exploitation of African timber especially after the end of World War I. For example, the United Nations estimated that timber deficit in Western Europe would grow from 25 million m³ in 1948 to 28.6 million m³ in 1951, based on a deficit of about 22 million m³ before the war (Teillac, 1954). Europe needed timber and turned to its colonies.
Chevalier (1909) called on the French authorities and justified the necessity for France to look for overseas wood by declaring that France was late in that domain, since England was already extracting considerable resources from India. Bertin (1918) claimed that France’s national deficit in timber after World War I was about 8 million m³, equivalent to approximately of 1 Billion Gold Francs that the country would have to spend in order to satisfy the interior demand. The French authorities recalled the famous claim of Colbert in 1662: “France will perish due to the lack of timber” and insisted, “We must use the timber of our colonies…” The governor of the colonies was clear: “Germans understood that so well that since 1914, they built six sawmills fitted with modern equipment in Cameroon (Bertin, 1918).”

In 1918, a military prospection for a massive exploitation visited the coastal area, along the railway and a couple of logging perimeters. It recognized 800 species, specified their potential use and suggested two cutting strategies: 1) sporadic cut of selected species, in small quantities to sell at a very high price and 2) progressive spatial exploitation of all useable individuals along with the installation of trails, roads and tree farming. The mission also selected thirty-nine species to introduce smoothly on the French timber market. A first sawmill was built in Grand-Bassam in 1918 and a second in 1927 in Abidjan. Timber production took the proportions of a continuous international trade (Fig. 55). Albeit France was the major importer, by 1960 about half of the production went to other countries. Germany, Italy and the Netherlands together totalized about 1/3 of the exports and the United States, about 5%.

![Graph showing the export of timber by country during the colonial time.](source.png)

Source: Direction de la Programmation de la Budgétisation et du control de Gestion (1983)

Fig. 55: Repartition of Timber Export by Country Buyer during the Colonial Time
3.2 Mismanagement during the Colonial Times

By 1918, not enough was known about the forest, even though exploitation had already started. Chevalier noted the differences in the forest composition. Bertin noted that sporadic cuts had already caused the disappearance of many rare species from river banks. He underlined a bias in the evaluations due to the heterogeneity of the tree population and suggested that it was utopian to use simultaneously and suddenly all the species at the same time. How the sample data was extended to the entire forest to justify the cutting strategies is unclear. The difference in the tree composition and the disappearance of species appeared as simple comments and those aspects were not taken into consideration for the exploitation.

Technically, the colony was not equipped for commercial logging before the activity started (Normand, 1971). Loggers had to create their own trails often destroying the forest outside their concession to get the shortest access to the roads (Teillac, 1954). Accessibility issues pushed many loggers to request the vicinities of their concession in order to keep benefiting from their installations. Perimeters were poorly mapped, roughly delineated on maps that were not accurate and causing their distribution on the field to be equally inaccurate. It was usual that one logger found himself cutting in another one’s perimeter. The heaviest consequence was the waste.

Robequain (1939) states that out of 15 species harvested only three were exploited with method: *Khaya ivorensis, Khaya anthotheca, and Chlorophora excelsa*. According to Normand (1971), only about 68% of the whole capital value and potential of an individual of *Entandrophragma utile* was used. For an individual of *Nesogordonia papavifera*, that number was 42%. In addition, because of the humid climate, the trees not promptly evacuated decomposed quickly. Bad road conditions and mechanical problems regularly caused loggers to abandon a cut tree in the forest or on the roadside.

Another devastating characteristic was the “Exploitation Libre” (Aubreville, 1938) policy. Considered utopian in 1918, it later allowed loggers to cut every tree that satisfied a diameter condition (40 cm to 80 cm) in the exploitation perimeter (5km/5km square). How the shift occurred remains to investigate. The “Exploitation Libre” made the whole enterprise more profitable. On the field, exploitation was clearly not rigorous, lacked control and consequently, the waste was enormous.
3.3 The Forest Was More Fragile and Deforestation Was Deeper

Contrary to the overly optimistic view that exploitation could never deplete the forest, better knowledge acquired over time started to raise concerns showing that the forest was not uniform. The primary rainforest was rather rare and there were secondary forests due to human activities (Robequain, 1939). Aubreville (1949) observed patches of species from drier areas inside the rain forest and associated them with past climate changes and species migration; after cultivation of poor soils along the frontier of the rainforest, it was not the rainforest that reconstructed but bushes that grew; clearances could be invariably conquered by the forest or turned into a local savannah. The frequency of poor soils could be known only two decades later. The forest was being discovered as observations spread. Thus, it is only after almost 50 years of logging that the possibility of the forest’s permanent degradation became a legitimate concern. Meanwhile cash crop development had already started.

Chevalier (1909) set the first link between cash crop agriculture and the forest. Cash crops (cocoa and coffee) were in the hands of a couple of European settlers at the beginning of the 20th century. Later, a campaign led by explorers presented the rain forest as the most suitable region to grow cash crops under the idea that with the natural conditions similar to that of the Caribbean and the cheap labor force in place, an attractive pricing along with social actions would easily trigger their cultivation by the local people. Production increased along with cultivated areas (Fig. 56).

![Graph](image)

Source: Direction de la Programmation de la Budgétisation et du control de Gestion (1983)

Fig. 56: Exports (a) and Area (b) of Cocoa and Coffee in Production during the Colonial Time
Cash crop production actually sheds light on the deforestation before 1958. Indeed, cocoa and coffee trees take a couple of years before entering into production. Coffee can take up to 10 years to enter into full production (Chevalier, 1944). The production could have never soared at the same time the timber production did in 1958-1960 unless the plantations were created before. Data may reflect more the bookkeeping related to the status of the Cote d’Ivoire as “Exploitation Colony” and a lack of assessment.

The end of the colonial period is marked by the first exhaustive aerial photography between 1955 and 1957 at 1/50000 but no land use map was produced. The topographic maps created distinguished between forest, degraded forest, bushes, and reduced agriculture to a few plots. They show a remarkable greenness of the land; 75% of the forest was said still intact (Arnaud & Sournia, 1980) which was actually not likely. Then again, it was on that ground (also generalized) that the next period started.

4 The Green Mine of the Côte d’Ivoire after 1960

4.1 More Deforestation

The period from 1960 to 1983 saw the rise (1960-1970) and the decline (1970-1983) of the Côte d’Ivoire’s economy. According to data, timber production soared, resulting in more exports (Fig. 57).

![Exports (1000 Tons)](source: Direction de la Programmation de la Budgétisation et du contrôle de Gestion (1983, 1984, 1985))

Fig. 57: Export of Timber Products

After 1960 was a time of fast urbanization: 94% of the urban population (980,000 people in 1965 and 2,146,300 in 1975, using charcoal or fuel wood on the daily basis) were in cities located in the forest,
which increased demand for food and energy sources. In addition, the overall development of the country, which increased demand for timber for school furniture and construction, also increased the local consumption. Forest products remained the third source of export of the country until 1984 (Sayer et al., 1992) and 60% of harbor activities and traffic (Arnaud & Sournia, 1980).

Agriculture was not the only or even the major cause of deforestation. Data about other causes is just not available. What likely happened was that if logging accounts for a one time cut, cultivation targets the land and keeps it for a longer time (Winter-Nelson, 1995), making the use more visible. Even currently, no one knows the proportion of the land under cultivation in the deforested areas.

Normand (1971) reported that loggers picked individual trees “selectively” unless harvest was actually the first phase in the creation of a plantation, which led to a clear cut. Some estimates indicate that for each five cubic meters of log, one ha of forest was converted into agricultural land (Myers, 1983). However, this kind of information may be relevant only to specific corporate or government plantations. The local people stuck to their slash-and-burn cultivation, which actually preserves number of trees. In addition, loggers regularly revisit the harvested perimeters (Arnaud & Sournia, 1980) to collect the trees that have grown to the right diameter. Logging was therefore not always followed by cultivation.

Plantation areas effectively increased led by a strong government campaign encouraging the development of cash crop mainly coffee and cocoa. Estimates show that new plantations were created which sometimes exceeded in area the pre-existing ones (Fig. 58).

![Fig. 58: Evolution of the Areas of Cocoa and Coffee (Estimates)](image-url)
Agriculture extension was certainly a fact. Since yields remained quite stable, production increase implicitly meant an increase of cultivated areas. However, spatial data is too often extrapolated, generalized or assumed instead of being the result of ground measurements. Spatial data created was mostly at a local scale, driven by the needs for urban planning and government operations. By 1966, a new estimate established that forested areas had decreased by more than 40%.

4.2 Resource Mismanagement was based on the Use of Obsolete Data

The first exhaustive vegetation map specific to the Cote d’Ivoire (Guillaumet & Adjanohoun, 1971) filled a large gap. After 70 years of industrial exploitation, the document gave a better idea of the deforestation. However, it shows the types of vegetation following the typology of Yangambi (Letouzey, 1969) and is not a land use map. The legend never uses the term “deforested” or “degraded forest.” It is all about forest and forest under logging or cultivation.

Technically, the document was produced from air-photographs and various topographic maps created between 1956 and 1966, complemented with terrain observation around 1968 then simplified to 1/500,000 based on maps created using air photographs from 1956-1957. The abuse made of that document created the unfortunate situation in which obsolete data became the reference for the forest policies. The government estimate of 1966 gave around 9 million ha of forest (Arnaud & Sournia, 1980). Interestingly, that information is very close to the statistics produced from the map (Table 5). Contrary to the estimate that 75% of the forest was still intact by 1956, we found between 64% and 60%.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Without coastal zones and mosaic forest-savannas</td>
<td>If all the coastal zone was forest</td>
<td>Including coastal zones &amp; mosaic forest-Savannas</td>
</tr>
<tr>
<td>Chatelain et al.</td>
<td>13.670</td>
<td>NA</td>
</tr>
<tr>
<td><strong>Our Calculation</strong></td>
<td><strong>13.735</strong></td>
<td><strong>14.350</strong></td>
</tr>
</tbody>
</table>

Numbers are in million ha; NA = Not Available

Table 5: Deforestation Level in 1956
In any case, if effectively about 2.8 million ha were cleared between 1956 and 1966, then by 1966, only around 43% of the forest was remaining at the beginning of 1967. In addition, the map shows 3.313 million ha under logging. The forest not classified as “under logging” or “under cultivation” was only 5.383 million ha at best by the time the document’s publication in 1971.

The problem is that, it was at that time that the government initiated the “Ivoirization” of the timber exploitation and industry (which was mostly in the hands of foreign companies) by bringing into the exploitation more Ivoirian loggers. The policy turned into a forest perimeter trade in which the newcomers, not equipped for the job, were only taking perimeters only to lease them. The boost for more exploitation came at a time when the resource in fact was in much less abundance than thought.

The numbers provided by government agencies and other studies are much more difficult to understand. For example, Arnaud & Sournia (1980) note 2,646 exploitation permits by 1969. Each allowed logging for 5 years to 15 years and the total area covered was therefore 6.6 million ha. By the end of 1974, the number of permits was about 3,000 for the total area of 7.5 million ha.

However, the third estimation made in 1974 gave between 5.4 million to 5.5 million ha, which is closer to the number in 1968 in our calculation. In addition, the area under exploitation in official notes was the area of the logging perimeters, not the actual lands effectively under logging which were 2.873 million ha. Those estimates without a clear land assessment were not enough. Each statistic went along with an uncertainty mostly related to the fact that what was happening on the terrain was unknown or just disregarded.

In summary, the document giving a nationwide picture of the land provided statistical information that was outdated by the time of its publication. The policies that used it were completely in contradiction with the reality of the land. It is more likely that the drama of the Ivoirian deforestation after Independence Day in 1960 unfolded during that period from 1960 to 1968. The inadequacies between terrain reality and the estimates heavily contributed to the decisions that resulted in the high deforestation. Even though those decisions could have been made in good faith, ignorance of the reality such as the cases observed in other tropical countries (Ascher, 2002), made them detrimental to the forest.
4.3 Forest Decline Became Official in 1976

The volume of exports drew more attention on the possibility of the collapse of the timber industry. Around 1927, the export volume of *Entandrophragma utile* was about 500 m$^3$, but it became about 10,000 m$^3$ in 1950, regularly rising, soaring to 173,631 m$^3$ in 1960 and 747,717 m$^3$ in 1968 (Normand, 1971). The author concluded that at that rate, production would “dangerously” decline since the volume remaining in the forest was estimated at 5.5 million m$^3$. In 1972, export of that species was limited to 500,000 m$^3$/year. In 1976, the reduction of exploitable areas and the dilapidation of the forest along with the weakness of the reforestation policy became official but nothing was done until the end of the presidential term 1975-1980. It was not until 1981 that restrictions and campaigns publicly showed the level of emergency (Table 6).

<table>
<thead>
<tr>
<th>Year</th>
<th>Regulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1981</td>
<td>Ban on <em>Chlorophora excelsa</em> and <em>Entandrophragma utile</em> logs export. Preprocessing required (to enhance secondary wood processing industry, increase employment and add export value).</td>
</tr>
<tr>
<td>January 1982</td>
<td>All species exports placed under quotas; exporters must obtain an export allocation.</td>
</tr>
<tr>
<td>April 1982</td>
<td>Log exports from open woodland (savannahs) and marginal forest areas (northern and central Côte d’Ivoire) prohibited.</td>
</tr>
<tr>
<td>1983</td>
<td>Log exports from concessions allocated to the processing industry prohibited.</td>
</tr>
<tr>
<td>1984</td>
<td>The export tariff on hardwood logs increased.</td>
</tr>
<tr>
<td>1991</td>
<td>Institution of a monthly auction system for log export quotas.</td>
</tr>
<tr>
<td>1993</td>
<td>The export of all logs was placed on a system of quota.</td>
</tr>
<tr>
<td>October 1995</td>
<td>Total ban on the export of all hardwood logs except teak logs.</td>
</tr>
</tbody>
</table>

(Extracted from Koudou & Vlosky, 1998)

**Table 6: Some Restrictions Imposed to Regulate Timber Exports**

Table 6 shows two time periods: the first from 1980 to 1985 and after 1990. A deep political and economic crisis marked the period between 1985 and 1990. Attention focused less on resources management policies, while actually one of the factors at the foundation of the crisis was the economic recession due to the high depletion of the natural resources. The paradox is that, during that time the government launched a new policy encouraging the return to agriculture in an attempt to reduce the unemployment rate. The officially discourse did not give a reason as to why the policy failed but it circulated that the reason was the “lack of arable lands,” which was to say that there was no more forest.
In fact, a big dichotomy has always made official discourses difficult to understand. For example, there is confusion in the use of the term “forest land.” At times the term “forest land” means the land that is covered by an existing forest, but that understanding quite regularly tends to encompass all the lands originally under forest cover in the country, whether the forest still exists or not. The confusion led to many environmental policies such as the wild fire mitigation activities and even desertification projects. For example, during the years of high drought 1983-1984, wild fires propagated into the formerly forested areas, but then deforested through the dry Chromolaena Odorata (L. King & H. Robinson). Much of the official discourse talked about “forest zone fires” and drew a straight line to forest fires. Not all the fires in the initially forested area of the country actually burned a forest but even to date the same discourse continues to fuel environment policies.

Since 1981, everything has changed in the discourses about forest resources exploitation and management. The period between 1985 and 1990 was certainly very detrimental since most of the control and surveillance infrastructures were weakened by the lack of government authority. Clear and exhaustive inventory of the deforested lands was no longer optional by 1980, but the country has not conducted one yet. Assessment focuses on specific places in the context of industrial plantations’ creation, urban planning and development projects.

4.4 After 1990

The recent forest assessment focused mostly on protected lands seen as the only valuable forest remaining in the country (Achard et al., 2002). Official statistical data produced from that cartography is far from the true reality. Chatelain et al. (2004) demonstrated that actually in many cases, there was more forest outside the protected land than inside. The documents produced not only pose a problem of data but also recall the problem of the use of the new technologies of information, especially Geographic Information Technologies and Remote Sensing data.

Indeed, the cartography used GIS- and Remote Sensing data but two issues arose. The first was the technical choices related to the scale of the output, which is 1/200,000. The legend displayed two land
use and land cover types along with their proportions in each polygon even though at that scale, it was still possible to produce information that is more detailed. In addition, the relationship between the scale itself and the purpose of the project aiming at assessing the state of depletion of forest resources is unclear. Chatelain et al. (2004) concluded that it is better using smaller scales, since a major part of the forest is comprised of the patch of smaller size. In the sample area they studied, they discovered that 30% of the total forest coverage is made of patches of less than eight ha. Entities of that size are somewhat difficult to make visible on a map, especially at the country’s standard scale of 1/200,000. The national cartography services used modern geographic information technologies, but did not map them despite the praises (Bassolé et al., 2001).

The second issue relates to the entire notion of forest assessment. The result maps are used with the same mindsets established before colonial times. An assessment mostly centered on protected areas was turned into the assessment of the forested lands in the country, and from that, forest policy makers have inferred and constructed management strategies using strongly biased information.

One astonishing aspect of forest policies in the country is the lack of support for forest perimeters not considered as government property. Despite the numerous discourses relating the local people and local government to the management of forest resources, policies are unidirectional, all pointing to state-protected lands, not only making them the only target for clearers but also completely designating an essential part of the forest capital as irrelevant. The vast majority of the resource is not counted in the country’s natural capital, never assessed and therefore unknown and disregarded by policy makers.

The period after 1990 even with the use of modern spatial data collection technology, did not change much in forest management and policies in the country.

The country ratifies many of the United Nations Organization conventions such the convention on desertification or climate change. Police enforcement on protected areas was strengthened and wild fire mitigation agencies were created. In total, the country had made strong efforts to implement structures that can actively respond for field activities. However, between policy and technical choices, forest and deforestation affairs did not escape the mistakes made decades before since data is not correct.
5 Conclusion

Forest resources exploitation and management have been at the center of many debates for decades; we have insisted that deforestation is a clear fact and the causes are multiple and known. However, policies and decisions that initiated and drove the process were not grounded on reliable data. From the misconceptions and overly optimistic opinions at the beginning of the 20th century to the inadequate technical choices at the end of the same century, deforestation in the Côte d’Ivoire is an overall mismanagement story based first on poor quality data and mindsets. The exploitation did not go along with an assessment strategy. At each step in the deforestation process, data used to construct policies was obsolete or assumed, or consisting of simple unfounded political statements.

Why no clear assessment was conducted is still a mystery that will not bring the forest back; what justified the technical choices will probably be also hard to discover; however, when information was available, decision-makers took measures aimed at mitigating the disaster. There is therefore hope that if accurate data is provided, policies can be better. With the current stage of deforestation, it is imperative to construct an assessment strategy capable of providing accurate spatial data before policies are engaged.
References


Chapter 7: Deforestation and Managerial Scales in the Côte d'Ivoire

1 Introduction

The forest of the Côte d’Ivoire has been almost entirely depleted. Many political, economic, and social reasons have been put forward as the causes and factors that drove the process (Ehui, 1993). The reduction of the forest capital commands its evaluation and integration into economic models for a good estimation of the country’s economic health similar to other countries (Winter-Nelson, 1995). However, one compelling aspect too scarcely mentioned and counted as a cause of the deforestation is the set of managerial scales used to organize the forest exploitation on the field. Managerial scales are spatial units used to partition space into controllable areas for resources evaluation, valuation, exploitation and management (Mendoza & Prabbu, 2003).

In the Côte d’Ivoire, forest exploitation has taken place in square harvest perimeters of 2,500 ha since the beginning of colonial times. Around 1968, a new unit was added whose size was 1750 ha. Officially, a fragment of forest of less than 100 ha is not considered as forest in the “productive meaning of the term” and but “degraded forest” (Arnaud & Sournia, 1980). A degraded forest in that case is not necessarily a forest under cultivation or exploitation of any kind, but systematically no longer classified as part of the country’s forest domain because it is “hardly profitable and subject to fast disappearance.”

How far those standards or definitions have changed since they were set could not be discovered in this research. However, if they are still in use, then we should remark that actually it may have become extremely hard to find such a one piece 100 ha block of forest outside of the protected lands. In reality, even inside the protected areas not all of the forests meet that criterion.

Chatelain et al. (2004) observed in different sample areas that, on one hand, patches of less than four ha comprise up to 30% of the forest coverage while on the other 14 fragments can represent up to 75 % of the forest. Clearly, the country is in another dynamic. There has been a shift from the large primary forest units to a large number of smaller units. Forest destruction in the country did therefore not have the same intensity everywhere even though the policies were the same everywhere. Economic and political
reasons certainly motivated policies, but how they translated into space, especially through the spatial units, can shed some light on the spatial patterns of deforestation.

It would be hardly deniable that the size of the exploitation perimeters also had an impact on the financial decisions made by the loggers and other economic agents having an interest in the exploitation of the forest or of its land. As a matter of fact, if prices were set based on cubic meter of timber, many other taxes and exploitation fees were based on the size of the perimeter, and finally, the profitability of the overall timber production system was also based on the total harvest collectable in perimeter. Unfortunately, usual analyses tend to give less attention to field operations and their relationships with the deforestation and subsequent financial mechanisms.

We argue that the mechanism of defining and positioning the logging perimeters and relegating portions of forest to non-profitability was an important cause of the depletion of the Ivoirian forest.

In this discussion, we will first attempt to insert the deforestation dynamic in a formal forest fragmentation scheme, second, we will explore how spatial units played in the commerce of timber and contributed to the deforestation, and third, we will discuss and comment on how they could have even influenced policies through their use for spatial data creation.

2 Method and Data

We explored manuscripts and reports from government agencies, archives of the ministry of agriculture and colonial monographs.

We also used two sets of Landsat satellite imagery. With the two sets, we created two image mosaics. The first mosaic aggregates scenes ranging from December 1985 to April 1987 and the second, scenes from December 2001 to February 2003. They both cover only the southern part of country usually considered forested land in the country. Data availability and cloudiness actually dictated the choice of that period. Under the assumption that a forest that exists later surely existed before, we considered the result as most reflecting the state at the earliest time. We assumed that the first set pictures the state of the land cover as by January 1986 and the second as by January 2002. We then classified each scene by
maximum of likelihood. Protected area in each scene or an adjacent one served as reference. Our focus was more to exhibit a general state with more emphasis on the unprotected areas, and therefore, we did not preoccupy ourselves with differentiating forest plantations from natural forests.

We also scanned, georeferenced and digitized a map created by Chevalier (1912) and another map constructed by Guillaumet & Adjanohoun (1971). With each of those documents, we created two class (forest, non-forest) maps. The map of Chevalier is originally at 1/3,000,000. Some parts were very difficult to catch visually. In addition, the frontiers of the Côte d’Ivoire were not clear, since at that time, the space was still part of French West Africa. We used therefore the current limits provided by the ESRI in ArcGIS. The map of Guillaumet & Adjanohoun at 1/500,000 is a nationwide data.

3 Analysis

3.1. The Model of Forest Fragmentation

Studies that focused on the loss of the forest and its associated social and economic causes actually generated many statistics. However, we note that deforestation is a spatial process evolving usually by phases that one can map at different scales: local, regional, and country level. The distribution of spatial phenomena across space and time usually gives clues about the foundations and dynamics of the issues at hand and can even inspire some solutions. Yet, in that aspect, very few documents about the deforestation in the Côte d’Ivoire exist. Often, only the landscape at a given time or at best two phases, is presented exhibiting views that are sometimes rather exaggerated (Rekacewicz, 2002). Beyond the statistics therefore, the question remains which is whether the deforestation process has followed steps or phases that one can fit into a theoretic spatial framework.

In this study, we are discussing deforestation in the Côte d’Ivoire in the context of forest fragmentation theories. Many models exist that illustrate forest fragmentation stages. Some cases, picture degradation levels as a spatial succession of lands with different proportions (size and number) of forest fragments. Another view can present how the successive phases actually occurred in the same place through time and which we attempt to distinguish in the next paragraph (Table 7).
Table 7: Stages of Forest Fragmentation in the Côte d’Ivoire since 1900 (based on Gergel, 2006)

<table>
<thead>
<tr>
<th>Terrain View</th>
<th>Year</th>
<th>Stage</th>
<th>Model</th>
<th>Description</th>
</tr>
</thead>
</table>
| Before 1850  | 1         |       |       | **Perforation**  
The Northeast and the center of the map show clearances that are visible even at 1/3,000,000. Perforation might have been higher than that but not hidden by the scale of the map. |
| From 1904    | 2         |       |       | **Incision**  
It happened around 1904 with the railway construction. A dozen of loggers were already harvesting. There were also running under the forest’s canopy. |
| By 1910      | 3         |       |       | **Dissection**  
It was complete by 1910 with the railway running through the forest and separating it into east and west sections in addition to several roads. The damage by 1910 may be higher than the stage of dissection. |
| By 1955      | 4         |       |       | **Dissipation (map)**  
Fragments are clearly isolated but can still be mapped invariably and be seen at small cartographic scale. The central part of the country is almost cleared out. No documents between 1912 and 1955 |
| 1986         | 5         |       |       | **Shrinkage**  
Only fragments of a certain size can still be mapped at small cartographic scale. The majority would require a medium or even large scale to be seen. Protected areas are clearly isolated. |
| 2002         | 6         |       |       | **Attrition**  
Another cartographic strategy is necessary to avoid the misconception that it is a desert. The number of small patches increased and it is not clear whether the patches are forest remnants or secondary forests. |
Stage 1: As long as the Côte d’Ivoire was perceived in the context of the French West Africa, stage 1 looked more like the first stage in the fragmentation scheme proposed by McIntyre and Hobb (1999) in which the presence of one poach is not enough to speak about fragmentation (Fig. 59). According to that schema, in such case, the forest is still “intact.”

Fig. 59: Forest of West Africa (Extracted from Chevalier, 1912)

Perforations of a certain size cannot be seen at the scale of 1/3,000,000. Within the limit of the Côte d’Ivoire, spatial differentiations are more apparent in the Northeast and the center. Cocoa and coffee were cultivated in the southwest near Liberia. Slash-and-burn agriculture and commercial logging existed by 1672 (Bulliet et al., 2010). It is hard therefore to tell when Stage 1 really happened.

Stage 2 can be set with the railway construction that started in January 1904. While existing roads ran under the canopy, the railway opened the canopy. Logging companies (about 13) also created entrances. The “Compagnie forestière” was already harvesting from a 60,000 ha perimeter (Bertin, 1918).

Stage 3 was complete when the railway reached the northern limit of the forest and separated the forest into East and West sections. The railway construction cleared about a 100 m wide path and used wooden traverses shaped with the tree cut on site.

The period between stage 3 and stage 4, unfortunately without any map, has been marked by the construction of sawmills in Grand-Bassam in 1918 and Abidjan in 1927. The railway and its adjacent roads became main timber production areas. By 1918, a road from Dabou in the South to Bouake in the center of the colony partitioned more the forest. Logging perimeters were distributed on about 1/7th of the
forested area. Prospection reached the northwestern limit of the forest in 1932. By 1948, concessions spread all along the colony's coastline (Teillac, 1952). Many preserves were defined during that time. The demand for fuel wood and charcoal in cities increased the quantity of timber sold on the local market.

Stage 4 exhibits fragments of different sizes, cleared zones in the center and near the Southeast. The Southwest was still mostly untouched. There were many zones of connectivity between the fragments but some were completely isolated. Deforestation had already reached the northern frontier of the forest.

Stage 5 occurred probably by 1975. We show it here with an image from 1986 but in actually a rough assessment in 1974 concluded that less than 1/3 of the forest remained. A number of restrictions or bans went into effect to regulate or prohibit the logging of some species by 1980. Much of the initial distribution of the forestlands was no longer discernible. Paivinen et al. (1992) produced a map of the situation in 1980 that already displayed the protected forests isolated, similar to our map.

Stage 6 was definitely reached before 2002 and probably even by 1990 reason why the national assessment of 1990 did not consider the lands that were not under government control. Forest fragments were so small that even with modern tools it was still hard to map them correctly. An amazing amount of patches of less than 100 ha dominates the landscape and distinguishing between noise and actual land cover unit is not evident.

Deforestation in the Côte d'Ivoire has effectively gone through stages in time and space. The beginning and the current phases are clear but the stages in between are not evident mostly because of the lack of better information. Nonetheless, we do not see a progression from the south where it started towards the other regions. Exploitation spread based on the location of the logging perimeters. It is hard to tell where deforestation actually started and where it was heading. Some areas in the center of the country were as much deforested as in the south, so that it is almost impossible to establish clear regional differences in the level of deforestation. Even by 2002, some areas more deforested in 1986 seem to be recovering and present a different spatial pattern. At country level and excluding a few areas such as the Southwest, it looks more that the depletion happened everywhere with comparable intensity and almost at the same time, which may find explanation in the logging strategies.
3.2 Three Managerial Scales Shaped the Fragmentation Schema

3.2.1 Forest Heterogeneity, Logging Conditions and the Market

Exploitation used three managerial scales, one fixing the minimum exploitable size and two others fixing the size of the logging perimeters. We could not find an official justification for those choices. However, they could be explained by practical production capacity and economic reasons.

Indeed, the forest was heterogeneous. The number of individuals varies per species and per hectare; the species did not have the same commercial value (Table 8). The number of species logged increased over time first because of the evolution of the market and second because the decline of the first class species trees forced the loggers to look for alternatives. When the first class species timber lacked on the market, log buyers did not find any difficulty using the second-class specie timber (Teillac, 1952).

<table>
<thead>
<tr>
<th>Species</th>
<th>Average Individuals/100 ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Makore Thieghemella heckelii</td>
<td>3 to 7</td>
</tr>
<tr>
<td>Tiama Entandrophragma angolense</td>
<td>6 to 7</td>
</tr>
<tr>
<td>Aboudikrou Entandrophragma cylindricum</td>
<td>6 to 7</td>
</tr>
<tr>
<td>Acajou Khaya Ivorensis</td>
<td>10</td>
</tr>
<tr>
<td>Sipo Entandrophragma utile</td>
<td>14</td>
</tr>
<tr>
<td>Niangon Tarrietias utilis</td>
<td>300 to 400</td>
</tr>
<tr>
<td>Avodire Turreanthus africana</td>
<td>500</td>
</tr>
<tr>
<td>Samba Triplochiton scleroxylon</td>
<td>More than 500</td>
</tr>
<tr>
<td>Iroko Chlorophora excelsa</td>
<td>4 to 10</td>
</tr>
</tbody>
</table>


Table 8: Number of individual per species per 100 ha

Timber price abroad was quite variable on the market due to various factors. For example, the loss of the American market in 1952 created a higher offer in France. In such conditions, buyers bought the first quality timber at the price of the second quality species.

However, we note that the price of the second-class species’ timber tended to stay stable and low while the first class timber species’ price could jump very high all the sudden. For example, there were no Mahogany exports during the first semester of 1951. The species appeared on the market during the second semester selling at 30,000 Francs/Tons, climbing to 34,000/Tons during the third semester, dropped at 22,000 Francs/Ton during the fourth, and disappeared the next. The same trend appears in
1950 and to a lesser extent in 1949 (Teillac, 1952). Teillac (1952) reported also that the sellers tended to avoid long-term contracts. Indeed, given the humid climate causing the logs to putrefy quickly, the lack of appropriate conditioning and storage facilities, and the competition that will clutter the market and lower the price, log sellers needed to act fast. In fact, the Free-On-Board system of timber trade was mainly a response to the environment-based timber quality deterioration but it guaranteed the quality of the product only to the buyers. For the loggers, the best option was a living stock always ready along with fast harvest; the size of the exploitation unit was useful in that case.

3.2.2 The Size of the Exploitation Can Relate to the Species-Based Costs and Benefits

According to Teillac (1952) the production cost by 1951 was roughly between the equivalent of current $7.30/m³ to $15.66 /m³ (Free On Board). The sell price to the local buyers was between $6.52/m³ and $8.70/m³ whatever the species, but between $9.78/m³ and $21.74/m³ when exported.

If the logger could harvest a second category tree at the lowest cost and sell it at the highest price on the local market, then the profit would be around $1.4/m³. However, a high valued log harvested at the highest cost and sold overseas at the highest price would give $6/m³ net profit. For the high-valued logs exported, the logger never lost substantially if he could sell around the average selling price.

Because of the forest’s heterogeneity, a higher concentration of valuable tree species in a close range reduced the production costs. Instead of one large area with a content whose quality was not always guaranteed, the managerial scale proved small enough to allow loggers starting exploitation with high spatial flexibility almost everywhere, squeezing harvests around most profitable sectors after prospection.

Manageable size perimeters positioned according to the species allowed quick responses to the market. Loggers could locate the sectors based on species concentration, ask for exploitation permits and wait for the demand on the market. The annual evolution of the price and exports of Mahogany described above is an illustration. The markets could even get clogged very quickly due to intensity of the harvest.

Because of that price variation over time and per species, harvest intensity based on species was also very variable over time and space. In that situation, the number of perimeters helped. Some
companies could get more than 100 exploitation units totaling more than 250,000 ha but distributed across the land and waiting for exploitation. Manageable perimeters but in high number helped maintain production capacity according to the market’s evolution.

The spatially anarchical location of the logging perimeters appearing as multiple perforations was therefore the result of a market-driven spatial implementation. The Côte d’Ivoire was an exploitation colony and the logging regime was the “Exploitation Libre” (Aubreville, 1938). Even currently, the system of “anarchical” location is still visible in the logging areas (Fig. 60).

![Logging perimeter and Access trail](image)

**Fig. 60: Authorized Logging Perimeter in a Protected Area in 1986**

Straight trails run deep in the forest and target a specific concentration of species, often disregarding species even of secondary categories in favor only for those in the target plot. Where the exploitation perimeter was located did not matter much but what went on inside it.

A second managerial unit went on use by 1968. Temporary exploitation permits allow logging on perimeters of about 1,750 ha. Loggers mostly used them to revisit their past perimeters and collect trees that have grown to the legal specifications after their previous harvest (Arnaud & Sournia, 1980).

Even though political and technical reasons were used to defend that size, we argue that terrain realities that allowed less the multiplication of the larger perimeters, actually justified it. In fact, if the government justified the scale as a policy to increase the number of Ivoirians citizens in the timber industry, those who received those perimeters sold them, which could have been the same if the perimeters were located in genuine forests. First regulation quotas were set by 1972. By 1974, a
nationwide estimate showed the heavy reduction of the forested areas. There was a need to look at what was left behind. The new scale looks therefore more like the mark of a tentative adjustment of the exploitation to the state of the natural stock than like a mark of fairness search.

One can measure the impact of the logging industry on the forest over time. After more than eighty years of heavy exploitation squeezed on the richly populated sectors, a smaller scale capable to constrict around the smaller fragments of forest left between deforested areas came to sustain the production system. Fragmentation had reached stage five in the model (Table 7).

In that same line of argument, we note that by 1981, pre-processing was required for some species, which could have been done before especially since, one of its goals was to increase the export value. The change in policy looks like a response to the reduction of the stock; it aimed at compensating the loss encountered in selling smaller quantities by increasing of the selling price of the same good.

Another aspect is that the set of measures and bans did not affect the location of the perimeters, which remained to the good will of the loggers. That aspect looks like an attitude ensuring the freedom of movement in the collection of the good that was becoming more and more scarce.

By 1968, the great forest abundance was gone. Even if the second managerial scale had a political dimension, technically it served better the interests in the context of rarefaction of the timber resources.

### 3.2.3 The Waste

An official note established the last managerial unit, stating that the minimum size allowable for logging activity was 100 ha of forest. The official reason that such forests are too “difficult to exploit, subject to quick disappearance” is quite intriguing. Technically, it is rather hard to imagine how 100 ha of forest could be more difficult to exploit than another of 2,500 ha. In fact, it is harder to think about how exploitation could even leave a plot of that size behind, given the averages in table 8.

Our opinion is that difficulties were certainly not about the terrain but about the assumed incapacity for such a forest to provide the minimum profit. Those fragments resulted from the species-driven installation of the logging perimeters. Loggers went from places of high concentration of better-
values species to another. Normand (1971) noted that effectively loggers worked selectively, picking trees from one place to another. In fact, logging in the Côte d’Ivoire was no different from logging in western countries with single species forests when it came to species exploitation. The trade market targeted individual tree species but in the case of the Côte d’Ivoire, such operation took place in a context of highly heterogeneous population. Unless all the individuals of every other species encountered while trying to reach the one on demand had a market value at that precise time, given the exploitation strategies, the waste was inevitable. The rush to the more valued species tore the forest into parts, making it look like a succession of large holes with the space in between them left devastated.

In some places, the first managerial scale poached the massive forest and the second went then on for the fragments remaining in the degraded area. The minimum exploitable size of 100 ha finally relegated the leftovers (even if well preserved) to agriculture, clearance and natural deterioration. The numbers in Table 8 are therefore very general averages. On the field, the number of exploitable trees could be far smaller, to the point where loggers could disregard a block of forest.

Probably, one of the most deplorable aspects about the managerial units is that no information shows how they contributed to reintegrate some fragments or regenerated forests back into the official national natural stock. We do not have knowledge about a policy aimed at reassessing the deforested areas to re-create a stock of manageable naturally regenerated forest patches. This aspect makes the whole system look like a model of economy that does not create stocks since the national reforestation program was not capable to provide alternate provision. The forests stand more like strict extractive natural resources.

We remark therefore that the fast fragmentation of the forest was also the result of the relationship between three factors that are first the heterogeneity of the tree population, second, the price and the size of the exploitation units, and third how loggers used those units on the field. Those units were not ecosystem management units, but commerce management units guaranteeing the minimum benefit. They all worked at reducing the stock of natural resources.
3.3 The Managerial Scales and Spatial Data

3.3.1 The Topography Issue

It is important to note the lack of clarity as to whether the size 5km x 5km was the actual field measured size considering the topography. Mostly likely, they were bird-fly distances measured on the map, and therefore the area effectively covered on the ground may have been much larger than said. Contrary to monographs, the forested area of the Côte d’Ivoire is not topographically a plain but a succession of hills and elongated lands separated with valleys and real mountains in the West. It is almost impossible to get a flat space of 5km x 5km outside of the coastal area and consequently the positioning and delineation of the logging perimeters on the field bore strong inadequacies.

During that time, cartography was prospection-based and concentrated on harvest perimeters. Technically, it consisted in plotting the location of the perimeter using ground references on maps that according to Teillac (1952) were not always precise, but that for the time allowed an approximation of the location of the concession. Areas calculated from the maps were approximate because of the topographic issues.

Almost nothing changed even after the first air-photography coverage. Cartography remained perimeter-based when it came to forest exploitation. The series of base topographic maps at the cartographic scale of 1/50000 (created from the first air-photograph coverage) brought more confusion. With the topographic contour lines at 20 m interval, the land looked even flatter on maps, corroborating the mistake that the forested area is a plain. Arguably, confusions between the general altitude above sea level and the land’s topographic morphology supported such view. The I.G.N. topographic maps (1959) gave therefore better information but had their shortcomings. Locations were certainly much better, but the area issue remained unresolved.

The most recent GIS and satellite imagery-based assessment of 1990 brought even more confusions. On the maps at the scale of 1/200,000, the 40 m contour interval strengthened the idea of flat lands.
3.3.2 Map Scale and Managerial Scale

The official documents show some relationships with the official definition of degraded forest.

Given the current state of art of the cartographic technology, there are usually at least two common automatic ways to consider the threshold of 100 ha in a cartographic assessment. The first is the systematic elimination of all polygons of less than 100 ha and the second, a majority filtering with a 33 pixels by 33 pixels window. We chose one of the classified image scenes (path 196 and row 96) used to study the fragmentation model and performed a 33 x 33 pixels majority filter (990 m are close to 1 km) therefore tentatively simulated a 1 km square majority filter. The result amazingly gives some insights about the maps of the assessment displaying the large empty areas (Fig. 61).

The issue is quite complicated because every cartographic construction is project-driven and in that case, technical choices are pertinent in regard with the objective of such project. The map scale may therefore not be a technical cartographic mistake. Political and managerial choices may have governed these options. Besides, the dependency of the content of the map on the scale is not always that rigid and can be managed to offer better information.

![Fig. 61: Comparison Between Official Managerial Scale-based Filtering to the Initial Image](image_url)

a) Classification by maximum of likelihood  
b) Majority filter 33 pixels x 33 pixels  
(Screen shots not at scale)
The filtering removes all small fragments, leaving the largest ones and accentuating the seeming dichotomy of a forest/non-forest space comprised with tightly closed and well-preserved forests isolated in a clear-cut deforested land. The area of the forested lands decreases by 51% after filtering. Eliminating systematically all patches of less than 100 ha shows almost only the protected lands. The difference with the initial map is staggering and demonstrates how the scale can play a part in the construction of the faulty or at least disputable statistics about the forested land and the Ivoirian timber industry.

This example gives an idea of how far the official spatial statistics and numbers about the deforestation can be more political and in contradiction with the field. A compilation of the maps from the 1990 assessment became even and unfortunately an iconic picture and example of the tropical deforestation (Rekacewicz, 2002). Reality was quite different from the message conveyed.

### 3.3.3 Shape Matters

The nationwide cartographies typically use the scale of 1/50,000, 1/200,000 and 1/500,000. Generally, the minimum of 100 ha is sensibly a 1 km by 1 km block of forest, certainly with some variations in the shape. There are numbers of forest fragments of 100 ha that can be regarded as not fulfilling the criterion such as sets of fragments not completely connected but that together can exceed that threshold size. A forest 100 m wide and 10 km long may be classified as degraded while another one, 500 m wide and 2 km long may not be, even though both have the same area. In fact, a 100 m wide x 10 km long forest will not even appear on a map at 1/200,000. It would require an entity of at least 200 m width (1 mm on the map) to be visible. How officials and loggers effectively used that criterion on the ground deserves to be reexamined.

Shape and size together have a weight on the resilience of a forest stand. That aspect seems to appear under the idea of “rapid destruction” in the official definition of a degraded forest. Many studies, have examined the lengths of the short and long axes of forest fragments or patches with the objective of determining the capacities of such forests to withstand dismantling processes. There is therefore a clear possibility of quick destruction of the forest fragments (Chatelain, 1996). However, forest patches of less
than 100 ha without human history exist in the deforested area. From a logging and cartographic points of view, how does one differentiate between them and those resulting from the logging?

The lack of uniformity in the treatment of the different cases of less than 100 ha forest and the inexistence of official studies to support that value still make the definition hard to follow.

In total, the set of managerial scales had their impact on the deforestation process even though they operated at different levels and on different spaces. In fact, each of them fits the objective for which it was set well. When there were plenty of forests, exploitation used large perimeters but when the resources diminished, the smaller scale fitted better the smaller exploitable spaces before leaving the land almost empty of profitable trees. We also observed that the managerial scales are too restrictive and work only in one way since to date it does not appear that they have helped re-incorporate some regenerated forest fragments back into the official forest capital. That aspect in our view is probably the most appealing of the uses of those scales, especially in regard with the current level of deforestation.

4 Conclusion

Scale issues have always been at the center of debates in natural resources management. In this discussion, we looked at the case of the forest exploitation in the Côte d’Ivoire. The country underwent a high deforestation and currently, main discussions focus on what to do to protect the remnants and recuperate what could regenerate. We presented the deforestation stages in a formal forest fragmentation model to show that deforestation progressed from multiple exploitation areas and discussed how the game of the different managerial scales contributed to the shaping of the stages. Three managerial scales worked one after the other to poach and dissect, clear and then relegate the space to other activities.

We also underlined how those scales worked only to clear the forest and never worked at reintegrating resourceful spaces back into the national patrimony. It was definitely a good policy to have managerial scales for exploitation but it is also good to use them to develop resources. Their values need to be reexamined in the context of the current deforestation level with the idea of bringing together economic, political and scientific perspectives.
References


Chapter 8: Active Database for spatial Data Multi-scaling: A Case study of the National Park of Azagny in the Côte d’Ivoire.

1 Introduction

Deforestation is a compelling issue in the Cote d’Ivoire (Mendoza & Ayemou, 1992, Repetto, 1993). The total area of forest left in the country is critical, below the 10% threshold (Lambin et al., 2003). To stop deforestation, the government has undertaken a nation-wide program that gives to natural parks the role of biological diversity conservation stations. However, natural parks have been under pressure since the 1970s due to the decrease of forests and the lack of interest in the deforested lands. In fact, deforested lands are undervalued, excluded from national assessments and left to agriculture.

Since the 1990’s though, many studies have raised awareness on the forest patches that are present in the deforested lands (Chatelain et al., 1996) but overlooked (Achard et al., 2002). A reason why those forests are getting more attention is that in terms of policy making it is possible to either focus on one single large forest area or on a set of several small ones (Lovejoy, 1997) or both. Actually, given the level of deforestation, the country has interest involving every piece of forest in its policies.

However, the issue seems to be the difficulty to map the forest fragments especially at the standard cartographic scale used in the Cote d’Ivoire (1/200,000). Chatelain et al. (2004) proposed therefore the use of local scales. We note that in the past, local observations extended to larger areas have been a major contributor to the policies that shaped the forest’s depletion. It was not until around 1974 (Arnaud & Sournia, 1980) that a regional assessment brought awareness on the level of deforestation. Local studies were therefore important but only the regional scale study triggered decision-making.

As the seemingly opposite views on scale is feeding a new line of debate, we argue that the problem may be more about how data is constructed and presented in the map documents rather than in the sole value of the scale. Modern automated cartography has its frontiers. For the case of the deforested lands, a different approach in automated mapping is necessary since the current techniques to produce maps at smaller scales are detail-elimination-based. Such techniques will clean the small patches of forest
from the maps and present deforested lands as valueless. What is needed is rather a strategy that ports details across scales so that at smaller scales, and shows evidence of forest patches on the map documents used for management and decision-making. We decided in favor of active database systems.

This study will use the case of the national park of Azagny to how the problem of scale comes to be and how a different way of constructing spatial data might help. The first part presents the park and the scale issues and second shows a cartography that bridges the multiple views.

2 Methodology
2.1 Study Area and Data

The study area (96,645.45 ha) is centered on the park. From a reference point (22 m elevation) located at the center of the park (Fig. 62), we measured roughly 20 km toward the Nord, East and West.

![Study Area](image)

Fig. 62: Study Area

Different data are available. A map from Chevalier (1912) at the scale 1/3,000,000 gives some information about the forested areas in the area at the beginning of the 20th century. Topographic maps (I.G.N., 1959) at scale of 1/50,000 based on the first aerial photography coverage (1956-1957). Base maps are still the master documents of the park’s managers. We clipped, geo-referenced and digitized on screen the portion covering the study area. Guillaumet & Adjanohoun (1971) give some details about the
vegetation types along with whether they were under cultivation or not. That document is at the scale of 1/500,000. Satellite imagery classified by maximum likelihood using the Ikonos imagery (1 m resolution) as support is also in use. We distinguished 10 classes.

2.2 Scaling Method

The scaling method built on an active database management system, uses a set of techniques to keep information about to be lost in the map through a mechanism of concurrent data model change and data aggregation.

Active database systems (Paton & Diaz, 1999; Paton, 1999) are capable of watching a database and reacting to particular conditions occurring in the database. To accomplish such tasks, they use a knowledge model and an execution model. The knowledge model uses different rules made of three components: an event, a condition and an action.

We created a database using Microsoft SQL Server based on the concept of profile. The profile is a geometric representation of an entity. It can take different shapes, such as polygon, point or line at the same or different scales depending on its device coordinates. For example, the conversion from real world coordinates to device coordinates can cause all the vertices defining a polygon profile to have the same device coordinates. In such a case, we change the profile to point. If the result is two sets of vertices having the same device coordinates then we change the profile to a line segment.

At each scale change, a database trigger fires a routine to recalculate the device coordinates of the vertices of each profile and two additional angle-based techniques run to clean the cluttered areas on the map. When a profile becomes too small to represent, the system finds nearby entities of the same model and derives new features with them; otherwise, the entity having the isolated profile is integrated into a neighbor. During that phase, a routine ensures the collection of all information pertaining to the integrated features and uses it afterward to recalculate the attribute values. With that method, it is possible to automatically extract different layers of information according to the geometry types and manipulate them separately.
Our preoccupation is only with the visibility of spatial entities in the map. We use two mapping options. In the first, we create a dot map with the profiles of forests that reduced to points and overlaid it on the regular cartography after eliminating all the features whose profiles had reduced to points from the initial map. In that case, we did not perform any data integration. In the second option, we derived new features with the dot map, integrated data and mapped the features according the importance of the land use and land cover types. In that case, the entire map displays only polygons.

3 Analysis

3.1 The National Park of Azagny

3.1.1 Deforestation and Scale Issues

Forest protection in the Côte d’Ivoire began in the early 1910’s, essentially to support timber production (Meniaud, 1922; Aubreville, 1938; Guillaumet, 1967; Verdeaux, 1998; Ribot, 1999). A service of forestry created in 1912 established a forest domain reserved to timber companies. The reserve of Azagny (≈ 26,000 ha) was defined in 1926 and reclassified as partial reserve for the wild life by 1960. Fragmentation led to the proposition of new boundaries in 1972 by which the park would have lost about 6824 ha (26.24 %). Those limits were not officially accepted, though presented on recent maps as the official and current ones.

Poaching continued after 1972 and led to additional adjustments of the boundaries in 1981 and distinguishing two parts: a protection zone of about 2,604.65 ha of which 227.33 ha outspread on the Ebrié Laguna and a strictly protected area of 19,087.32 ha. The park, (protected and protection zones together) officially lost 17.63% of its original extent but gained 375 ha through the East and Southeast parts by the protection zone. The new lands added to the protected zone give an area very close to the official 19,400 ha. The protected forest was raised to the rank of national park in 1981 along with a new policy centered on eco-tourism in 1984. The eco-tourism project failed, the protection zone became more deforested. Around 1992, different studies suggested its complete inclusion it into the park for better surveillance (Fig. 63). Currently, the situation of the protection zone in the official view is quite unclear.
since it is not even mention it as part of the protected area. The park has been declared a biological preserve, placed under permanent monitoring and handle from multiple perspectives denoting the struggle to manage it as part of a continuum of ecosystems.

![Diagram showing changes in the National Park of Azagry from 1955 to 1981.]

**Fig. 63: The National Park of Azagry from 1955 to 1981**

At times, policies present the park and its vicinities in the context of the marine ecosystems along the West-African coast, which is a sub-continental standpoint. However, some reports mention that 85% of resources extracted around the park feed markets outside the vicinities and thus place the park in a regional view. However, the eco-tourism project shows it as an isolated site of environmental interest.

The protection zone exhibits the same issues. In practice, the role of the protection zone has always been unclear. It was defined as part of an early detection strategy to stop poaching. Different discourses also portrayed it as a deforestation containment territory, part of the regional economic system; the idea was then to keep it as a land of sustained land use to guarantee the integrity of the protected area. However, underneath those aspects was the hope to see it reforested which would make it one of the largest coastal parks on West African coast.

There are therefore embedded perspectives ranging from the local to the sub-continental and suggesting the search for a strategy of integrated scales ecosystem management. In that case, we argue that what is a strategy that conciliates all parties by porting enough information at each scale of intervention.
### 3.1.2 Evolution of the Forested Area Since 1900

Before the park’s creation, the area exhibited a high potential for timber exploitation. Chevalier (1909) listed valuable species, *Kaya ivoriensis* and *Entandophragma utile* intensively exploited after the Bertin mission in 1918. The mission mapped additional high valued species such as, *Mitragyne ciliata*.

According to I.G.N. maps (1959), the region was still in the original vegetation by 1955. However, after 1960, it became one the chosen regions for the government’s cash crop (coconut and oil palm) plantations. Plantations were created preferentially in the savannahs (Guillaumet & Adjanohoun, 1971). They drew the development of the living crops to support the growing population. Some cities previously established on Atlantic shore moved to the hinterland because of the sea level rising.

By 1986 (Fig. 64), forest fragments of 10 ha or less make up 99.65% and 2002, 99.54% of all the forest fragments. In 1986, the fragments of area between 1 and 10 ha make 23.41% of the forested area. In 2002, that proportion is 46.3%, while fragments of 200 ha make 29.54% of the forests in the study area. Since 1970 therefore, there is a tendency to generate smaller and smaller forest patches in the area.

**Fig. 64:** The Forested Lands in the Park of Azagny and its Vicinities around 1986 and 2002
By 2002, the total forested land was about 18,445 ha. In the vicinities, 36.95% of the forest existing 1986 was cleared. Most forest remnants outside of the protected area are wetlands (Table 9).

<table>
<thead>
<tr>
<th></th>
<th>1955 Area (Ha)</th>
<th>%</th>
<th>1986 Area (Ha)</th>
<th>%</th>
<th>2002 Area (Ha)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Park</td>
<td>13,502.46</td>
<td>21.34</td>
<td>7,566</td>
<td>31.66</td>
<td>7,666</td>
<td>41.56</td>
</tr>
<tr>
<td>Protection Zone</td>
<td>272</td>
<td>1.14</td>
<td>654</td>
<td>3.55</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vicinities</td>
<td>49,771</td>
<td>78.66</td>
<td>16,057</td>
<td>67.2</td>
<td>10,125</td>
<td>54.89</td>
</tr>
<tr>
<td>Total</td>
<td>63,274.3</td>
<td>100</td>
<td>23,895</td>
<td>100</td>
<td>18,445</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 9: Forest Proportions in the Park and its Vicinities

Forested lands less or equal to 100 ha represented 99.98% of the forest fragments of the study area and 84.23% of the forestland.

3.2 Map Documents

3.2.1 Point-Based Map

We observed that after conversion from real world coordinates to device ones, 75.86% of the profiles of the entire study-area were reduced to points. Of that proportion, 44.40% are forest and degraded forests. More than 1/3 of the entire area could no longer be mapped as polygons. That proportion represented also the fraction of the information susceptible to be lost.

At that stage, it was mostly how those points were distributed or clustered in the representation that determined their visibility in the map. We ran a three-pixels by three-pixels majority filter to reduce the cluttering of the map at the scale of 1/200,000, but that procedure sank 86.23% of the forest fragments in the area outside the park.

However, extracting those points in a new layer using our method made their representation easier. The forest patches in valleys and humid areas along the rivers and water bodies, with some of them being mangrove are more distinctive (Fig. 65). Moreover, the central swampy part of the protected area is exhibiting a large number of forest patches that could not be seen.
Fig. 65: Dot Representing Forest Profile Reduced to Points

Fig. 65 shows the information susceptible to be lost from visibility when the map is at the scale of 1/200,000. The dark areas are just points appearing as clusters, mostly because the other land use and land cover entity types separating the dots are not mapped. They are present almost all over the map in clusters of different sizes that show the density of forest patches in different parts of the study-area. It is not even visually clear that there are more dots in the deforested lands than in the protected areas or vice-versa, which confirms that those patches may not be only the result of a fragmentation of the initial forest by deforestation. The swamps actually show individualized patches of various sizes more shaped by the waterways and the topography. Some patches can be regenerations or secondary forest patches.

Anyhow, the most fundamental aspect is how those patches are so invisible in the regular cartographic document (Fig. 66-a), even though we mapped them in the document with the same color and same dot size. We overlaid therefore the dot layer to the map for comparison. The visual difference is quite stunning. The regular cartography (Fig 66-a) effectively portrays the area as completely deforested with a couple of blocks of forests principally isolated in the very few wetlands.

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Fig. 66: Comparison between Regular Cartography (a) and Dot Map Added Cartography (b)
The view looks rather like a desolated place, emphasizing the large agricultural blocks and barren lands. Only the park and the northwest vicinities capture the attention with the presence of a set of isolated blocks. Even the view of the forest inside the park is rather minimalistic. It shows two large blocks of forest in the matrix of less forested land, and emphasizes much the non-forested lands. The forested area in the park resembles an oval-shape isolated between the shrub and croplands in the north, and savannahs and swamps in the south.

The regular cartography gives a pessimistic portray of the terrain that thus looks completely deforested. One should note that except for the corporate- or government-owned agricultural block, the local people practice slash-and-burn agriculture, which never clear-cuts the trees. Accessibility issues also limit the clearance and cultivation possibilities of the local people to topographically amenable areas. The regular cartography therefore presents the land as a place where no real forest policy can be viable except inside the park and cultivates the lack of interest in the deforested lands.

The dot map on the opposite limits the exaggeration. It presents the land as effectively heavily deforested but not completely clear-cut and tree-less. For example, the deforested area in the East of the park is still clearly marked but the few forests in that area are well visible. Some other areas more homogeneous can still be delineated. The northern portion of the protection zone invisible in the regular cartography looks more integrated to the park and it transitions to the non-protected area with different levels of degradation. The land looks here rather like a place where different dynamics are present, in the park as well as in the deforested vicinities.

The forested area inside the park looks more continuous and homogenous, which is the case. The texture of the image sinks fewer details, and the park is no longer cookie-cut in an environment of wasted lands. The west side of the park shows how the system of swampy forests stretches down near the coast line and involves the island inside the river. This view better displays the park in the context of the Atlantic marine ecosystems made of lagoons, wetlands, forests, mangroves and coastal savannahs.

By extracting the polygons reduced to points and mapping them in a separate layer, the map reveals better the existence and distribution of a number of forest patches.
3.2.2 Area-Based Map

The polygons derived with the points give another view of how connected the forest patches are (Fig. 67). With the threshold distance equal to three times the value of a device unit and half (about 88.27 m) at 1:200,000, 220 amongst 631 polygons are complete forest patches. Those whose major component is a forest or a degraded forest comprise 400 (63.4%) of the total number of derived features amongst which 169 (27.78%) were classified as forest.

![Derived Forest Polygons in the park and its vicinities](image)

Fig. 67: Derived Forest Polygons in the park and its vicinities

From our reference point, we overlaid a grid of 5 km by 5 km corresponding to the size of the standard logging concession. New polygons present a lighter density than the points in the dot map. Still, that option displays also the potential to exhibit and add more information in the map document. Beside the grid cells falling on the corporate or government owned plantation and water bodies, we do not see a cell empty of new polygons of forest or degraded forest. By associating the points through the line segments, we obtained similar results. The northern portion of the protection zone looks even more
forested than predicted except very close to villages with only rare places. More importantly, there are still about 320 polygons associating patches of forest and degraded forest in that area that is nonetheless abandoned from national statistics. The last national inventory did not even map it. With the matrix included, the areas are respectively 97.7 ha for the forest and 102.05 ha for the degraded forests the most common matrices for the forest-based polygons are degraded forests, shrubs, savannahs and palms but forest and savannahs for the degraded forests. Shrubs and palms are fewer in the case of the degraded forest.

In a deforested land, the matrix matters (Dunford & Freemark, 2004). In the vicinities of the park, three major vegetation matrices (savannahs, shrubs and palms) incorporate forest or degraded forest patches (Fig. 68).

![Fig. 68: Matrix Type-based Distribution of Forest and Degraded Forest Fragments](image)

Based on the number of polygons per matrix type, savannahs come first for both forest and degraded forest patches followed by the shrub and last the palms populated areas. For the two first matrices, degraded forests patches are in larger numbers, which is quite logical since those two land cover types are the result of the deforestation.

There were large and naturally existing savannahs and coastal savannahs in the area. The land is therefore naturally favorable for the development of such vegetation. Some savannahs are actually swamps resulting from the combined effects of topographic and soils influences. There is a strong
dynamic of that type of vegetation especially with the multiplication of barren land creation by the roads and corporate crop parcels. In those areas, terrains observations showed mostly degraded forests or grouping of trees sometimes hardly suitable to call forest stand.

Natural savannahs were almost all used for the development of corporate plantations. More persistent agriculture whether with modern techniques or not sometimes create fallows of herbaceous vegetation in which persist highly degraded fragments of forests.

Shrubs are also the result of deforestation mostly made of invasive species that colonized the land after agriculture or logging competing with grass-type vegetation. The larger numbers of degraded forest in those areas is therefore consistent with the history and dynamic that the land went through and which can be seen with their areas being larger than the forests. Those forest fragments can be very difficult to isolate in shrub lands. The structure of shrub lands often integrates many lianas that grow and cover even up to 6 m high trees. It is therefore possible that some regenerations and degraded fragments might have been assimilated to shrub lands during the image processing.

Shrub lands are the most complex and the most cultivated lands. Deforestation actually continues through slash-and-burn agriculture, fuel wood and charcoal production in those lands. It is quite reasonable that they display the lowest numbers of forest and degraded forest fragments and area proportions. Chatelain et al., (1996) gave a better description of the types of wooden vegetation that can be encountered in the shrub lands and that range from real forest fragments to very isolated trees or group of trees.

Based on the areas palm-populated spots have the largest coverage of forest with a very small one for the degraded forest. Indeed, often both palms and forests are intermixed. Palm-populated spaces are not very much cultivated because often palms grow naturally in packs of highlands in the swampy areas. Those areas are very difficult to cultivate with the manual traditional farming tools. The small proportion of degraded forests for the large proportion of forests can be explained therefore by the few human intervention mostly for fuel wood and naturally occurred degradation.
An also interesting aspect is the larger proportion of forest or degraded forest patches in the savannahs versus the other types of matrices. It is our opinion that this expresses the attention locked more on non-grass-based types of vegetation. Only the originally forested lands (evergreen primary tropical forest) capture people’s attention in the area mostly for the creation of cash-crop plantation (cocoa and coffee) as well as for logging. Fragments and regenerations even when they can be classified as secondary forests generally do not attract people’s interest. A forestation dynamic may be ongoing in the places considered less productive.

In terms of policy, the reality of the terrain still gives enough room for the diversification of protection and safeguard activities instead of the sole police enforcement and people resettlements. For example, it is possible defining corridors in the protection area. Clusters of forest and degraded fragments in the deforested areas can be isolated as zones of interest for refuge for the wild life based on a minimum mapping unit to facilitate their cartography and monitoring. The combination of the dot and polygon maps we built shows that the landscape still fitted for a conservation and protection policy based on defining sets of several small patches of forests in the vicinities of the park. In addition, a better knowledge of the deforested matrix still matters. In fact, given that the original landscape associated forest and savannahs why savannahs are so much absent in the management policies remains a curiosity. The analysis made here is based on the visibility of spatial features on the map so that it becomes possible to do more management analyses using more sophisticated spatial and forest fragmentation statistic tools.

Cartographically, the method used here allows creating new understandings of the landscape based on the combination of the matrix and its contents instead of, or in addition to, the conventional typologies. Given the structure of the current landscape, a cartography that allows the map-reader to construct compound definitions or typologies such as “Forest in Savannah Matrix,” or “Association Forest-Palms,” which are more combinatory, can be more pertinent than the classic land use types.
Fig. 69: Comparison between Regular Cartography (a) and Derived polygon integrated Map (b)
By 2002, the Park of Azagny was still not an island of forest (Fig. 69) in a desolated land albeit the high deforestation level. The land at that time had lost a very high proportion of its original tropical rain forest. However, by making the existing forest fragments more visible, it appears that the catastrophe scenario in which the land has been displayed was not consistent with reality. The park was still in a landscape made of an amalgamation of forests of different origins, sizes and location. The natural context made with a mix of coastal savannas, swamp and high ground forests was still visible.

4 Conclusion

Practically, natural parks management and protection have been at the center of many debates in developing countries, especially the Côte d’Ivoire where deforestation has reached high proportions. Natural parks play an important role in biodiversity conservation, and it is important that these parks and their surrounding deforested areas be clearly assessed and understood. There is therefore a need to seize and put on display every aspect of the land for better decision making. The search to study and portray the park and its vicinities from different perspectives is clearly evidence that local, regional and even sub-continental levels of understanding are necessary. Spatial data in that case needs to be more comprehensive and integrated rather than simplified or with fewer details.

This research is about the use of automated systems in spatial data creation. While most methods for map and data scaling in GIS rely on detail elimination by generalization, this research opts for detail conservation and integration. It uses a method that makes the quantity of information less dependent on the scale of representation. By using an active database system to manage spatial information, we avoided data elimination and created different levels of details, derived compound data and information and federated them to give a different picture and description of the area. This study shows that not only was the place still less deforested than described but improved management could have been initiated if information was better.
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Part 3: Case study: Multi-scaling the Park of Azagny’s Spatial Data: Ending Remarks

Spatial data creation has always been a problem in the Cote d’Ivoire. In the past spatial data was scarce, collected from local accessible areas. Exaggerations, generalizations and political propaganda exemplified the potential of the forest while minimizing the weaknesses. The country did not have its own assessment team and equipment for spatial data creation before more than 70 years of deforestation. It is probably logical that the catastrophe surprised all the users.

However, technically on the field operation not only commercial logging did not clear all the forests but neither did agriculture. Still, a natural dynamic of regrowth still occurs and consequently, deforested lands are not without forests. If before 1990, data might have been scarce, it was no longer the case after that date. Technical equipment and quality personnel available could have produced better data. Conversely, forest policies conceived with the mindset of total clearance. A reason is the too formal or straight use of data creation technologies that do not allow small size forests to be mapped. Those forests are simply hard to map using current multi-scaling tools because of their small sizes. Indeed technically, it can be simpler to eliminate the details in order to produce cleaner. To show those forests on a map, an out-of-the-box procedure was necessary.

The use of a method that integrates rather than eliminates small data allows porting small size forests across scales sometimes under different geometry types. It is therefore possible to map small forests patches at regional scales. We produced a set of maps that show that effectively, with such data, it is possible to devise better policies instead of the single police-based protection enforcement.
GENERAL CONCLUSION

Deforestation in the Côte d’Ivoire has been cited in many debates. Policies, exploitation and management activities have been examined in various ways and in this study, we have focused on spatial data used to design forest policies and make decision about the forest exploitation.

Speaking about forest and deforestation and dealing with them generally starts with collecting data related to them, analyzing such data and making decision based on such data. Studying a forest is the exercise of examining the information that has been gathered about it.

Data accuracy and quantity in that case, are extremely important since such qualities are the primary foundations of the adequacy between the knowledge created from data, discourses, decisions and policies and the reality. Data quality is therefore an aspect of forest management that should be handled with care especially when it comes to exploiting forests that can take a century or more to reconstitute.

Unfortunately, a major aspect of the Ivoirian deforestation is data unreliability. Until around 1959 where the first topographic maps were produced, it was hard to get a regional or nationwide accurate view of the forest. Even though the external boundaries could be mapped, the interior of the forest was not much known and was being discovered through exploitation notes, travelers and explorers’ diaries and the too few descriptive local studies by the rare scientists during their occasional visits of the by then colony.

Unfounded extrapolation, generalization, exaggeration and political propaganda based on those few local observations created the myth that the forest could never be depleted, which was not consistent with reality. Such inaccurate knowledge became a major cause of the inadequacy between the forest’s exploitation system and the actual resource available for extraction. Consequently, the depletion of the forest could not be avoided, surprised all the forest resources users and the safeguard of the few fragments of forest that could be saved became very problematic.

Clear and more reliable regional scale data was therefore necessary but could be not created before the mid 1970’s. When finally such data was created, it effectively gave an assessment that was close enough to the realm of the terrain to reveal the level already disastrous of the deforestation, and
trigger mitigation decisions. Regional data was and remain therefore important and how to create such
data has become thus one of the obstacles to overcome when dealing with the deforestation in the country.

The current situation on the terrain is different from the one prevailing during the 20th century but
in a very subtle way. If before the 1970s, it was the idea of inexhaustible evergreen rainforest that created
and nourished the mindsets in a context of scarce data, currently it is the idea of a totally deforested land
that feeds the same mindsets, but data is available along with technologies and qualified personnel to use
such technologies. The question was therefore where the mindset came from.

In fact, more than 80% of the original forest has effectively been destroyed in various ways and
the vegetation types that replaced the original forest are difficult to classify. In fact, the deforestation was
not the result of a system of clear-cut but of a selective tree harvest that collaterally destroyed lots of
forest without exploiting them. In addition, officially a forest fragment of less than 100 ha is not a forest
but a degraded forest and consequently abandoned from the official forest capital. Deforested lands are
therefore not without forest. They are comprised with a variety of vegetation matrices filled with forest
fragments of the initial forest, degraded forests and regenerations of different sizes, stages, dynamic and
value. Unfortunately, much of those forests are not mentioned in the assessments, which give to the
deforested lands the image of clear-cut and desert-like areas.

Many studies have argued that the reason why the forest patches are not mentioned in the
assessment is their small size. In fact, given devices constraints, some entities of small size can be hard to
map at regional scale. Sometimes the shape also can make such cartography very difficult. Scientists
therefore proposed rather the use of locale scales.

However, for one to what extents can local observations be extended to the entire country is
unknown. Second, local scale information is not always equivalent to detailed information, the second
depending more on choices made by the cartographer. Third, one way or another, the need for regional
views will require syntheses at lower cartographic scales especially since some of the causes of
deforestation are regional. Regional scale in that sense presents more advantages.
We argued that the matter is more about the cartographic principles and technology in use rather than in the value of the scale. In fact, conventional computer-based techniques present a limitation when it comes to creating cartographies at smaller scales. The reason for such inefficiency is that those techniques grouped under the chapter of map generalization in digital cartography are based only on information elimination. They seek to produce readable documents at smaller scales by reducing the quantity and quality of data. Smaller size entities and details along feature boundaries are eliminated or ignored to avoid map cluttering or simply because they become less visible.

The deletion based on whether a distance or an area condition is satisfied or not, does not admit intermediary situations and often the relationship between those measures and the cartographic scale is not clear. In addition, those techniques are single algorithm-based which either at the level of the shape or the attribute of spatial entities even though in many situations both levels need to be considered concomitantly. The amount of information loss depends thus on the number of details eliminated. As the cartographic scale decreases therefore, so does data reliability because of the increasing gap between that cartographic scale and the scale at which data has been collected.

With the current deforestation level and the amount of small size forest patches, such methods eliminate a high amount of data and justify the impression of clear-cut deforestation. There is therefore a need to find a cartographic technique that would conciliate data collection and analysis scale and cartographic or representation scale in order to provide more reliable information.

Our argument is that what is needed is a method capable to port detailed information from larger cartographic scales to smaller ones with the least information loss possible while producing maps that are less cluttered. We looked at the issue therefore from the angle of the scale as a mediator between reality and spatial data that represents, describes and speaks about it at multiple levels of abstraction.

We dissociated data scale from the scale of its representation and proposed a multiple-tasks oriented approach that will reconstruct spatial information as the scale changes. We devised therefore a new map multi-scaling method grounded on active database systems, tested its components on different areas of the Côte d’Ivoire and evaluated the final application using the National Park of Azagny.
chose that park as test zone because of the variety of landscapes its displays and its location marked by a very dynamic deforestation process resulting in its current isolation in the deforested vicinities. In the context where trees and forests are the value-making elements of space, those vicinities are considered useless and excluded from management and economic policies. The study was organized in three parts.

Part 1 scales and cleans a map. This phase is purely about the shape or geometries. Contrary to current detail elimination-based methods, it splits the geometry scaling into three techniques.

The first technique converts the real–world coordinates into devices ones and then filtering the vertices based on whether consecutive vertices have the same device coordinates or not. The map is then built using only non-redundant vertices. That exercise is repeated each time the scale changes. The results are better than those of the usual zoom-out and algorithms of vertex deletion. However, because of the polygon topology some entities are not mapped either for insufficient number of vertices or topological incompatibility. Areas and perimeters are modified but in acceptable proportions for the test-area.

The second technique aims to avoid pixel clustering along poly-lines, based on the idea that the cluttering is based on the value of the angles created by triplets of consecutive vertices belonging to the same line. The technique therefore reduces the line’s complexity by moving the vertex at the angle along the angle’s bisector. It enlarges the angle to the minimum value necessary to avoiding the clustering. For the test-area we note that the technique considerably reduces the cluttering and modifies the feature shapes but the areas and perimeters seem to stay rather stable across scales. Differently from map generalization methods, geometric changes are progressive at each angle, the value used to evaluate the condition for such modifications is calculated based on the scale and is scale invariant if expressed in device units. We also note that the vertices used as references (line beginning and ending points or points shared by more than two features) and excluded by the method can clutter the map at coarser scales.

The third technique uses the same principle as the second but acts on the reference vertices excluded by the previous method and can produce topological modifications. After the vertex at the angle is moved, the contiguous features are adjusted if necessary. The technique can create a variety of contiguity modification cases but does not considerably affect areas and perimeters.
At the end of this part, we note that the association of the three techniques proved capable to create multi-scale maps with less cluttering and highly improved readability. However, the case of the features impossible to map because of topological incompatibility could not be solved.

Part 2 examines the attribute values redefinition and integration and creates the active database. For the attribute value integration (chapter one of this part), we considered that a map is made of different components, graphic and non-graphic elements and that, as the scale changes, geometries that cannot be represented graphically can be translated into other elements of the map. Following that logic, entities that cannot be graphically mapped are integrated into others then, the attributes values of the new structures can be recalculated to avoid information loss. Different mechanisms for such data integration exist. After integration, we used a mechanism of layered legend to map the entity types present in each feature based on the importance of each type.

Chapter two of this section integrates all previous techniques to build the active database. The main idea is that, since as the map scale is coarsened some entities cannot be mapped and are ignored, distorted or dropped from the representation creating thus information loss, what is needed is a system that operates differently. We proposed a system that can be aware of the features about to be lost, captures, keeps them, manipulates their geometries and attributes in some ways and maps them at a smaller scale in a more readable form. Multi-scaling is considered a multi-tasks strategy which requires triggering techniques to execute the actions listed above when some conditions are satisfied and makes active database management systems more suitable candidate automated mechanisms. The chapters of part one and two of this document describe actions. In their of execution, these actions are 1) geometric scaling by coordinate conversion and filtering, 2) cluttering elimination line complexity reduction, 3) cluttering elimination by reference points displacement, 4) scale-based feature integration, 5) deriving polygons from features reduced to points, 6) deriving line segments from features reduced to points due to scale, 7) final integration of all created geometries and 8) attribute value recalculation to produce the final map.
Implementation of the database is based on the concept of profile understood as an abstract representation of spatial entities that can change geometry type according to the number of vertices and topology generated by the geometric scaling. The entire system was tested and as a result, the map document displayed improved readability with less information loss up to the cartographic scale of 1/200,000. Symbology design and application could not be associated to the automated procedure since we did not have a computer-based mechanism to evaluate the visual aspect of the map document.

At the end of this part, we got an active database system for automated map multi-scaling. That database stands as a multiple operations-based system where data is not eliminated but reformulated by either integration or derivation of new entities, in order to be kept in the map. It has been tested on a small area and the results are satisfactory in terms map readability and spatial information accuracy.

Part 3 describes deforestation in the Côte d’Ivoire and applies the new technique to show how it can help create better spatial data.

In chapter one of this part, we show that information gathered about the forest was too little before and during the colonial period. Subsequently the discourses about the forest and the forest exploitation systems based on unfounded generalizations were not in line with the reality of the field. Until 1974, the idea that official data rather made of sparse studies, localized, assumed or outdated information, was giving about the forest was far from the reality, reason why forest users were all surprised by the depletion of the forest by that year when the first regional and better assessment was produced. Creating reliable data continues to be a major issue even currently and faces a different challenge since the current environmental context is rather marked by deforested lands. The environmental context has changed but regional data creation methods did not.

Chapter 2 exposes how logger (a principal cause of deforestation) executed harvest operations on the field, how it created deforestation spatial patterns and finally influenced spatial data quality. With the lack of adequate timber logging, storing and processing equipment, a quick harvest was the answer to the market’s evolution. Harvesting combined three managerial scales and aimed to secure richly populated perimeters for rapid cut and delivery. The country underwent a high deforestation which stages that fit in
a more temporal formal forest fragmentation model. However, spatially, deforestation was rather more a spread dismantling than following a linear and progressive front. From different points of exploitation scattered in the forested area, commercial logging combined by cash crop development tear into pieces the forest so that by 1957 more that 60% of the forest was already destroyed and by 1970 probably about 2/3 of the initial area. Unfortunately, spatial data creation methods that did not change according to the level of deforestation. Ivoirian forest assessment and cartography services stuck to creating regional data using data simplification techniques. If such way of doing fitted with the official definition of a forest, and of a degraded forest, which are actually very debatable, conversely, it creates a total inadequacy between data and the realm of the terrain because of the smaller sizes of the current forest patches. Detail elimination-based regional mapping ignores the multitude of forest patches and produce inaccurate maps.

Now that the country is facing the risk of a total disappearance of the forest, different protection and management strategies operating at different scales were envisioned to stop the deforestation and to eventually initiate the forest’s reconstruction. However, the main activity remained armed police-based defense and safeguard of a set of protected areas such as the National Park of Azagny.

The deforestation progressed, reached and destroyed the vicinities and parts of the Park of Azagny, which like the other protected areas in the country, is currently presented as an island of forest in the vast deforested land by official assessments.

In Chapter 3 of this part therefore, using our mapping strategy, we reveal that the situation is not that catastrophic. In fact, assessment using regular generalization techniques tends to eliminate details and rendering emptier map document. The incapacity of such techniques to show detailed information at regional scales causes small patches of forest not to be represented.

With the method we designed, on can map those patches at local and regional levels. We could show that, deforestation has effectively destroyed the forests around the park. However, fragments of the initial forest and regenerations constitute up to 30% of the deforested land. Savannas and shrubs created from the deforestation concentrated most the forest patches. The cartography of savannahs and shrubs needs to be more careful because of the possibilities of confusions between the invasive species and the
degraded forests. Such confusion later makes distinguishing them on the aerial photographs and satellite imagery more difficult. Anyhow, by 2002, the park of Azagny was still standing in its initial regional coastal forest ecology. We also noted that different types of forest patches in the deforested could be used to define corridors, combined vegetation types that can help design different management approaches and bring therefore different alternative activities, instead of the sole police in the area. At regional level, it is possible to distinguish similar landscapes and diversify protection strategies.

The problem is therefore less the scales of cartography or study in use, but more about the techniques used to create the spatial data and represent it. With all the capacities offered by current Geographic Information Sciences and Technologies, it is possible to quickly calculate areas and perimeters, perform gap analyses and even more, and use them to produce better data instead of staying at level of quick generalizations and simplifications.

In any case, for a policy that would involve as many forest fragments or patches as possible, which in our opinion is the way the country should approach this issue, not only are data or detail elimination-based strategies no longer appropriate, but new or different typologies and more compound data construction, and data integration have become necessary. We have proposed active databases as an efficient way to achieve that goal.

The contribution of this thesis is therefore three-fold.

First, it is conceptual by re-examining the concept of scale, dissociating the scale at which data is collected and analyzed from the scale at which the results of such analysis is cartographically represented. In aerial photography-based cartography without zoom-in and out capability, the scale of representation is usually the same as the scale at which data is collected. However, in computer-based cartography, one scale can be taken for the other, which drives into many confusions. Zoom-in and zoom-out do not operate at the level of the data but at the level of the cartographic representation of such data. Multi-scaling is rather about the process of bringing, reformulating or simulating data as encoding in the database, at a different scale which can be independent from the scale at which such data is going to be cartographically represented. It is a process of data redefinition or re-modelling prior to its analysis,
interpretation and cartography. That is also, why local scale does not necessarily lead to the creation of a detailed map. How much details should be plotted is mostly a cartographic decision usually rather project-driven.

Second, the contribution is methodological, consisting of introducing new aspects into automated mapping and Geographic Information Sciences. By automatically selecting different types of geometry to represent the same entity as the scale changes, simulate some aspects of manual cartography, recalculating the map at each scale change the approach developed in this research is a new. Generally, device coordinates are calculated once then the scale is managed through the mechanism of the zoom-in and zoom-out. We consider that even though we reason in terms of real world coordinates, in the end, it is only what the map can show that creates the message that is conveyed and focused more on device coordinates. We also dissociate issues that pertain to scaling a map and those pertaining to the readability of the map, the second depending more on design strategies. The method is replicable and can be used to examine other cases as well; it proved very convenient for the case of the park of Azagny. Contrary to the single algorithm-based map generalization techniques, this approach combines a set of techniques to create better data and is multi-task oriented and rule based.

Third, the contribution of this research is about ecosystem management and forest exploitation policy. Forest are ecosystems existing in tight relationship with their environments. However, it appears in the case of the Côte d’Ivoire that they are not considered as such but rather as particular and isolated features participating to the landscape without any connection with the other ecosystems. We have showed that by considering the deforested lands as matrices for the fragments of forest, it is possible to get another view that is more profitable in terms of ecosystem management. The deepening of the deforestation required redefining the types of vegetation that were creating principally through more integrative and associative strategies. Unfortunately, data creator and policy makers failed to catch that that orientation and clung to typologies that were no longer pertinent. More than 50 years after the degradation of the forest, they are still using the classification that prevailed before