CONTRIBUTION TO THE CHARACTERIZATION OF FOREST FRAGMENTATION ON THE EASTERN FLANK OF MOUNT LEBANON OVER 33 YEARS

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(Received 13 January 2006 - Accepted 3 May 2007)

ABSTRACT

Fragmentation has become central issue in ecological studies as it is detrimental for biodiversity across the landscapes. It threats forest resources throughout the world. This study investigates the changes and fragmentations of the forests spatial configuration over 33 years (1965 forest map at 1/50,000 and 1998 landcover map at 1/20,000) at the Eastern slope of Mount Lebanon. Legends on both maps were first harmonized and entered into atypical forest fragmentation analysis. Spatial scale was then resampled for straight forward analysis. A set of landscape indices were applied to quantify changes. Junipers and oaks are the main forest types at the study area. The landscape over the study area showed to be highly fragmented and subjected to severe degradations. In particular, total forest area decreased by 47% (from 33,369 to 17,668 ha) during the investigated period. Patch number increased by 5 times, mean patch size decreased by 17 times and total edge has doubled. Inside-outside patch forest fragmentation analysis was used to detect the most degraded area and determine the forest regeneration dynamics. This paper provides significant contribution to the analysis of forest fragmentation in the Mediterranean environments using older forest spatial data toward the investigation of forest ecological conditions. Forest fragmentation analysis, however, requires lower level biodiversity investigations such as species level.

Keywords: fragmentation, forests, oaks, junipers, Lebanon, landscape indices, monitoring, landcover

INTRODUCTION

Although it is prominent that conservation of biodiversity is one of the pressing issues of this time, fragmentation of the forest ecosystems remains one of the serious causes of biodiversity depletion. Forest fragmentations are what happen when large contiguous forest patch splits into several smaller ones (Forman & Godron, 1986). Fragmentation is considered as an indicator of biodiversity loss (Wilcox & Murphy, 1985; Lauga & Joachim, 1992) through reduction of habitat area and breaking it into isolated pieces (Opdam *et al.*, 1993; di Castri & Younès, 1995; Hunter, 1996). In fragmented patches there maybe enough place for one or few individuals but not for a population (Burel & Baudry, 2003). Smaller forest patches get more susceptible to external disturbances than larger ones (Diamond, 1975; Nilsson and Grelsson, 1995).

Biodiversity loss and fragmentation are mainly due to physical environmental changes as a result of human activities such as logging, conversion of landscapes to agricultural land, overgrazing, mining, urban development, roads, water harvesting reservoirs, water diversion, etc (Hunter, 1996; Noss and Cooperrider, 1994; Reed *et al*., 1996). Forest fire might also contribute in fragmenting and degrading landscapes (Mladenoff *et al*., 1993). Important number of landscape metrics has been developed in literatures to quantify and monitor fragmentation of a landscape (McGarigal & Marks, 1994). Fragmentation analysis through landscape indices adds comprehensive concepts in the advancement of the forest patches (Franklin, 1994; Boentje & Blinnikov, 2007).

Lebanese government has acknowledged the importance of saving the biotic richness through signing the Convention on Biological Diversity (CBD) in 1992 and ratifying it in 1994. Abi Saleh *et al.* (1996) estimated that only 8% of the Lebanese territory is forests; the National Forest Assessment speaks about 13.3% of a total forest area (NFA, 2005). Although a country total forest coverage rate is a crucial index in monitoring forest resources, other indices are more informative (O'Neill *et al.,* 1988). In Lebanon, forests have been cleared through ages mainly because of human pressure in various forms (MoA/UNEP, 1996). Scientists nowadays are concerned to conserve what remained out of the older forests (MoE/UNEP, 1998). Since Landscape pattern analysis is not applied in Lebanon, it is important to analyze the history of forest stands and changes through time in order to better orient conservation measures. Forest fragmentations were not investigated in previous studies in Lebanon.

Existing landcover and forest maps of different years are valuable data sources that could be used to analyze forest dynamics and especially fragmentation. However, these maps usually hold different legends and spatial scales that should be harmonized before any computations. Landscape analysis is highly sensitive to changing map scale (Ferraz *et al.*, 2006). Inaccurate use of different spatial scale maps will definitely terminate into misleading results and consequently misinterpretation; this is especially the case when comparing landscape indices (Gustafson, 1998). Coarse spatial scale landscape representation usually indicates a landscape with lower fragmentation status (Saura, 2004) than if the landscape where studied on finer spatial scales.

Changing spatial scale on a map is not a straight forward procedure, and is mainly performed on urban blocks and roads (Zhilin & Choi, 2002) and to a lesser extent on forest spatial data. A standard generalization methodology or changing map spatial scale does not exist.

This paper provides considerable contribution to the analysis of forest fragmentation in Mediterranean environments, using available forest spatial data. Such forest spatial change analysis helps in future ecological management plans. Overall forest coverage is one important index that could be extracted out of spatial data sources such as existing thematic maps. Even if those maps were created by different authors of various backgrounds, for various purposes, and with various perspectives, they can be compared and used for ecological assessments if special treatments are undertaken.

MATERIALS AND METHODS

Study area

Situated on the Eastern shore of the Mediterranean Sea, Lebanon is part of the region which occupies the junction between Europe, Asia and Africa, with a surface area of 10,452 Km^2. The study area expands over 897 Km^2 of lands along the Eastern slope of Mount Lebanon with 81 Km north-south and 8-16 Km East-West (Figure 1). It had undergone important forest changes and landscape degradation (Masri *et al.*, 2002; Jomaa & Bou Kheir, 2003) and has been classified as subjected to high and very high desertification risk in Lebanon (CoDeL, 2001). Therefore, existing forests are fragile and had undergone irreversible degradation processes.

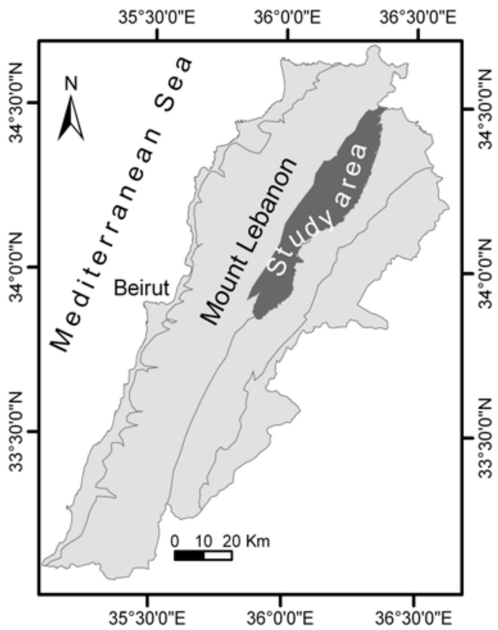

Figure 1. Location of the study area along the Eastern side of Mount Lebanon.

The study area is characterized by Mediterranean type of climate with vegetations of mostly presteppic formation. Forests are mainly oaks (*Quercus calliprinos* and *Q. infectoria*) and junipers (*Juniperus excelsa*) (Abi Saleh *et al.*, 1996). Soils consist of 52% red-soils and 34% of yellowish-mountainous-soils (Gèze, 1956). Rocks are mainly formed of dolomitic limestones that cover 92% of the study area (Dubertret, 1953). At the study area, annual precipitation is proportional to elevation and ranges between 300 and 1400 mm (Plassard, 1971). Elevation starts from 1100 m to the East and reaches 3050 m to the west. This large elevation gradient area fits within a distance of 16 Km, which have contributed in magnifiying the irreversible losses on the vegetation cover.

Data used

The used spatial data consists of two thematic maps: the 1965 forest map (1/50,000 spatial scale) and the 1998 landcover map (1/20,000 spatial scale).

(1) 1965 forest map

Forest mapping in Lebanon started with the aerial mission of 1962, which resulted in the production of the 1965 forest map at a 1/50,000 spatial scale (El Husseini & Baltaxe, 1965). Since then, and for the past 38 years, it has never been updated. The study area is included within six sheets that were merged and digitized using a geographic information system (facilities included in ArcGIS 9.2 software pack). Four different forest types were recorded at the study area: (1) oaks (coppice and stands), (2) pines, (3) cedars, and (4) junipers (Table 1).

TABLE 1

Forest Types at the Study Area in 1965

#	Forest type	Crown closure (%)	Species
1	Oak coppice	>30	*Quercus calliprinos, Q. infectoria,with or without some Pinus brutia, Juniperus and maquis spp in varying portions*
		10-30	
	Oak standards	>30	*Quercus calliprinos, Q. infectoria, Q. brantii, Q. cerris*
		10-30	
2	*Pinus brutia*	>40	*Rarely Pinus halepensis*
		10-40	
	Pinus pinea	>40	-
		10-40	
3	Cedar	>40	*Cedrus libani with or without Q. spp, Juniperus spp., and Abies silica, in varying portions*
		10-40	
4	Juniper	>30	*Juniperus excelsa, J. foetidissima, with or without Quercus calliprinos and Q. infectoria in varying proportions*
		10-30	

(2) 1998 landcover map

The existing landcover map of 1998 was derived from satellite images of IRS-1D (panchromatic 5 m spatial resolution) and Landsat TM 5 (30 m spatial resolution) (MoA, 2002). The IRS-1D image was merged to bands number 2, 4 and 7 of the Landsat TM 5, using the Principle Component Merging method. This process produced a False Color Composite (FCC) image (Refer to the map technical report for more details).

Legends concerning forests on the 1998 landcover map are generally separated between coniferous, broadleaved and open mixed woodlands with their coverage-density (Table 2).

TABLE 2

Summary of the Forest Types at the Study Area in 1998

General forest type	coverage	Forest types
Coniferous Woodland	Dense	*Pinus pinea, Pinus Brutia, Cedrus libani, Cupressus sempervirens, Abies cilicica*
	Clear	*Pinus* spp., *Cedrus spp*, *Juniperus* spp., *Abies* spp., *Cupressus* spp.
Broadleaved Woodland	Dense	Mixed woodland
	Clear	*Quercus* spp., Other type of broad leaves
Open mixed wood land	Clear	Mixed wood land

Semantic analysis of the legends

Legend comparison is a first phase when comparing different thematic maps. Semantic analysis of the legends of both maps is necessary to harmonize forest types to facilitate comparison. In particular, objects of same forest types but of different cover density were joined together in a GIS environment (Table 3).

TABLE 3

Harmonizing the Legends of the Used Maps

Forest legend (1965)	Legend harmonizing	Forest legend (1998)*
Oak coppice or standard 10-30%**	Oaks	Forest of *Quercus spp,* dense
Oak coppice or standard >30%		Forest of *Quercus spp*, sparse
Pinus brutia and Pinus pinea 10-40%	Pines	Pines dense
Pinus brutia and Pinus pinea >40%		Pines clear
Cedar 10-40%	Cedars	Cedars dense
Cedar >40%		Cedars clear
Junipers 10-30%	Junipers	Forest of *Juniperus spp*, sparse
Junipers >30%		

*Forest found at the study area.
**Percentage of cover density (see Tables 1 and 2).

Since, cover density on both maps can not be matched because a >30% forest cover in the 1965 forest map will not coincide with dense forest of the 1998 landcover map, legend harmonizing targeted only forest types.

Forest change analysis

An original assessment of the forest change was developed that opens the road toward using different spatial scale thematic maps for comparison purposes. The analysis was divided to what was defined as *(1)* inside-outside patch analysis and (2) forest fragmentation analysis.

(1) Inside- outside patch analysis

- In this paper, an inside patch analysis is defined as the investigation of forest changes within each older forest patch. Limits (edge) of each forest patch existing on the 1965 forest map were extracted and overlaid on the forest layer obtained from the 1998 landcover map. This step allowed us to search inside each forest patch of 1965 (old forest patches) what still exists in 1998. Although both maps (1965 forest map and 1998 landcover) have different spatial scale, their comparison became possible, using this inside outside analysis technique. Resampling of one map (raster format) to reach other map spatial scale using GIS conveniences could be a solution. However, this process accumulates errors and alters the map spatial data logarithmically which might not approach the real situations. Since any artificial modification in a map scale leads to errors, a comparison method is developped between maps that does not necessitate spatial scale changes. The important point is that the edge (boarder or limit) of a forest patch will have minor changes between maps of 1/20,000 and others of 1/50,000 spatial scale. These minor changes are, actually, simplification of edge complexity (Echeverria *et al.*, 2006) and not elimination of spatial information. Consequently, edges of 1965 forest areas were investigated from the inside using data of 1998 landcover map. Only limits of forests in 1965 were used and searched for changes in landcover.

- The inside forest patch comparison also provided landcover change matrix (transition matrix) and fragmentation analysis. Since only forest data of 1965 are available, the inside forest change matrix performed through direct comparison with 1998 landcover data. Changes of landcover on the inside of each patch were investigated in a table matrix.

- Fragmentation of each forest patch was inspected in particular approach. Landscape indices were calculated inside the 1965 forest limits using forest data of 1998. Number of the 1998 forest patches (Patch Number) inside the limits of the 1965 forest patch was the first indicator. Total forest coverage in 1998 remained inside each of the 1965 forest patches is also an important change examination for fragmentation analysis (Figure 2). Each forest coverage percentage in 1998 found on the inside of the 1965 forest patch is followed by Mean Nearest Neighbor (MNN) and mean patch size (MPS) calculations. MNN indicates the distance between patches, which when computed together with forest coverage for (inside) each patch will result to a further fragmentation analysis. Forest residues are named on the 1998 forest patches that were remained inside the 1965 forest ones. The forest residues MPS was compared to the original patch size (1965 patch size) and plotter of the residues patch number. This analysis separated the 1965 forest patches between different fragmentation degrees.

- Outside patch analysis was also conducted in order to know regeneration dynamics of the forests. The percent coverage of the forests in 1998 was calculated to the outside of the 1965 forest patches within the study area. New forests to the outside might be the result of regeneration or rehabilitation for the forest resources within the study area.

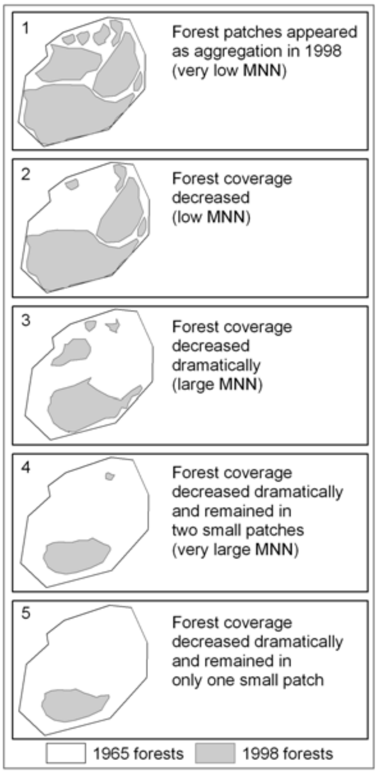

Figure 2. Comparison overlay between 1965 and 1998 forest patches.

(2) Forest fragmentation analysis

A general overview was required for the overall situation of fragmentation within the study area after considering each (inside) forest patch analysis. First, both maps were converted into raster format using GIS. Then resampling was performed to obtain two raster maps with 50 m pixel size each. This step degraded the spatial information of the 1998 landcover map to approach the 1965 forest map spatial scale.

This fragmentation analysis summarized the status overall the landscape. Quantification and fragmentation analysis of the spatial forest data were calculated based on a set of landscape metrics: patch number (PN), mean patch size (MPS), largest patch index (LPI), area weighted mean patch fractal dimension (AWMPFD), mean nearest neighbor distance (MNN) and total edge (TE). These selected metrics characterize the spatial fragmentation for the landscape. Patch number (PN) and mean patch size (MPS) should be used complementarily since high PN and low MPS values characterize fragmented landscapes (Leitao & Ahern, 2002). The LPI produces useful information of overall patch degree of change.

RESULTS

Changes in forest cover

Landcover change over the 33 year period was inserted into a transition matrix (Table 4). Over the entire period, agriculture replaced about 2% of the forests while only about 0.2% of urban occupied these forest areas. Grasslands have abolished the largest forest area that is about 20% followed by rock outcropping for about 5.6%. About 77% of oaks and only 25% of junipers persisted over the investigated period. Cedar forests shown on the 1965 forest map were not found on the landcover map of 1998. These forests were mainly replaced by junipers. Pine forests increased between 1965 and 1998 by about 62 times but they were not reported in the same geographic location. Pine forests located in the 1998 map have replaced some of the oaks and junipers ones.

TABLE 4

The Transition Matrix of the Forest Patches between 1965 and 1998 (ha)

1965	1998							
	Oak	Junipers	Pines	Grass-lands	Rocks	Agricu-lture	Urban	Total
Oak	11105.68	202.51	119.05	2018.92	452.11	301.85	62.35	14262.48
Juni-pers	697.62	5277.88	130.57	9456.60	4345.60	453.25	20.30	20382.27
Ced-ars	239.00	37.74	0.00	30.33	2.59	0.19	0.00	309.86
Pines	2.85	0.72	0.00	0.44	0.00	0.00	0.00	4.01
Total	12045.16	5518.85	249.63	11506.29	4800.30	755.74	82.65	34958.61

Forests in 1998 covered 17,668 ha, accounting for 18.7% of the studied area. However, forests in 1965 were in 33,369 ha or 35.3% of the total area (Figure 3). The studied landscape showed a decrease of the forest area by 50% within the investigated period (1965-1998). Patch number (PN) increased by about 5 times. Juniper forests were the dominant forest type in 1965 (Figure 4). Oaks showed important coverage, whereas pines and cedars represented less than 1% of the studied area.

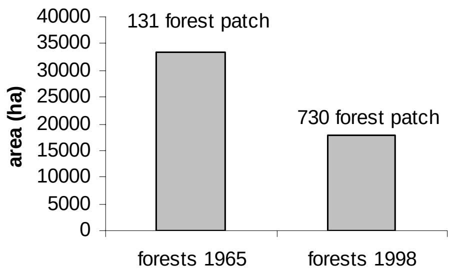

Figure 3. The total forest area in both years.

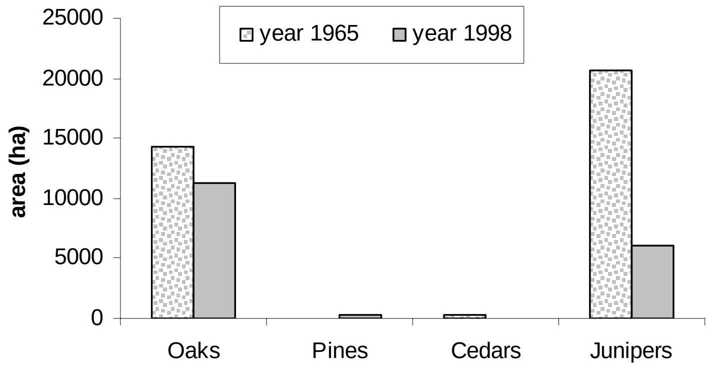

Figure 4. Changes of forest coverage between 1965 and 1998 by forest type.

Inside-outside patch analysis

About 55% of the 1965 forest patches have lost more than 50% of their original area by the year 1998 (Table 5). Out of the 131 forest patches identified in 1965, 15 have totally disappread in 1998. Moreover, 23% of the patches lost more than 80% of their forest area reported in 1965. Only 9/131 patches kept their original forest coverage, *i.e.*, no sign of fragmentation was detected.

The MNN ranged from 0 to 2 km between 1998 forest patches that are located inside the 1965 forests patches. Only 12 forest patches appeared to have very low MNN accompanied with large forest coverage. These 12 patches could be considered as somehow preserved or having witnessed minor changes.

TABLE 5

Forests of 1998 to the Inside of the 1965 Forest Patch Limits

	Forest cover in 1998 (%)					
	0	0-20**	20-50	50-70	70-90	90-100
Number of patches (%)*	11.5	23	20.6	19	19	6.9

* From the 1965 forest patches

** Excluding 0% forest cover.

Large number of 1965 forest patches had undergone important loss of size and significant segmentations into small patch residues in 1998 (Figure 5). The MPS of the residue forests formed mainly less than 50% of the original patch size of 1965. Very small MPS percentages are followed with high patch numbers which indicate complete loss of the forests.

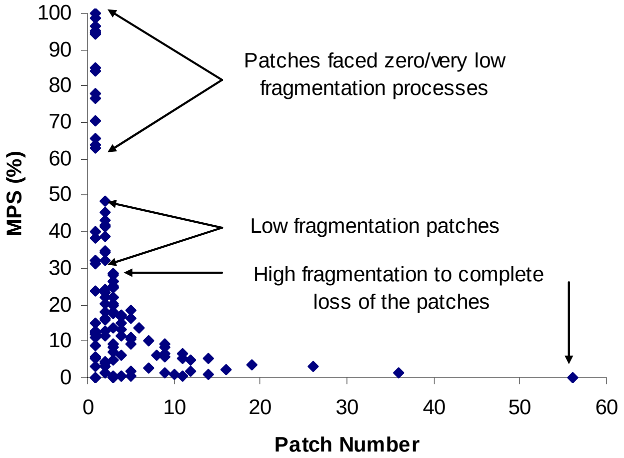

Figure 5. MPS percentage of forest residues from original 1965 forests plotted on their patch number.

Despite an overall dramatic decrease of total forest coverage over the study area, forest regeneration calculated as the increase of forested areas outside the 1965 forest patches, reached 4714 ha.

Landscape spatial analysis

The increase in number of the forest patches (from 131 to 730 patches) was followed by decrease of the patch size as the mean patch size index (MPS) determined (Table 6). The number of patches increased differently for each forest type. The patch number for junipers had increased by 10 times, while for oak it had augmented by 7 times. The largest patch occupied 45% of the total landscape (studied area) in 1965 while it decreased to 18% in 1998. These indices indicate that forest patches undergone important decrease in their size during the studied period. The AWMPFD demonstrates similar degree of shape complexity between the investigated years. The MNN decreased which could indicate better patch proximity or connectivity in 1998. In reality, this decrease in MNN is the result of large increase in the number of the small forest patches next to each other. The total edge increased dramatically with the increase in forest patch number.

TABLE 6

Landscape Spatial Indices for 1965 and 1998

Year	PN	MPS (ha)	LPI (%)	AWMPFD	MNN (m)	TE (km)
1965	131	861.4	45	1.21	157	955.4
1998	730	50.8	18	1.25	116	2120.6

Areas of severe forest changes were located to the north of the studied area (Figure 6). Junipers were largely affected in this part of the landscape.

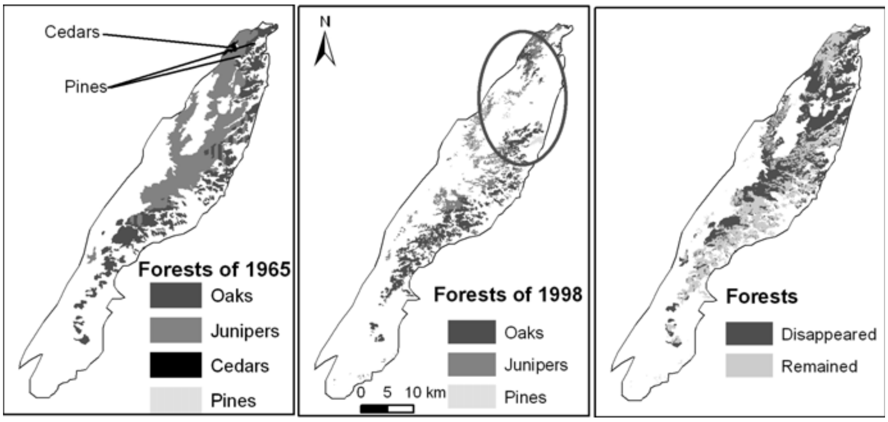

Figure 6. Spatial forest changes during the studied period.

DISCUSSION AND CONCLUSION

Forests at the study area have undergone severe loss as they were mainly changed to grasslands (Table 4), baring the prints of overgrazing activities and continuous human interventions by logging (Baalbaki, 2000). Rock outcrops have appeared within patches that were previously covered by forests which highlight the vulnerability of the top soil to erosion once forest cover is lost. These findings corroborate those of the desertification map of Lebanon scale 1/200 000 (CoDel, 2001) as the study area have been classified as highly vulnerable to land degradation and desertification.

Nor agriculture, nor constructions were significant as land use changes over the study area (Table 4). This is mainly due because the study area did not represent over the past year an attractive spot for farmers that preferred to cultivate the valleys and avoiding the harsh physical efforts related to terracing mountain slopes.

Oak species have the ability to grow new sprouts when subjected to grazing and/or cutting (Salleo *et al.,* 2002). This can explain why, despite intensive degradation, nearly 77 % of patches previously identified as oak stands in 1965, were still colonized by oaks in 1998 (Table 4).

Even though Juniper forests have often been reported in fragmented populations (Talhouk *et al.,* 2001), these results revealed a drastic decrease in their distribution as, over the studied period (1965- 1998), as much as three times their area have been lost. Informal discussion with local herders and mountain residents confirmed that juniper wood was largly used for home constructions in the late sixties.

Pine forests patches in the 1965 map were not shown in the 1998 map, whereas, pine patches located in different geographical spots over the study area were reported. It is highly probable that the patches identified as pine stands in the 1998 land cover map, resulted from plantation of pine trees.

Cedar forests within the study area disappeared during the investigated period. However, this result might be related to the fact that cedars were limited in 1965. These cedar forests are also surrounded by junipers which might have complicated the differentiations between both coniferous forests in a satellite image. However, such remote sensing and landscape analysis is always in need of field surveys in order to outcome conclusive findings.

The Eastern flank of Mount Lebanon had low forest coverage in 1965 and showed important forest degradation during the entire studied period. Over the study area, almost 50 % of the total forest cover has been lost in 33 years, mainly affecting juniper stands. Previous works, on the same area and time period, reported forest area decrease by 58% (Masri *el al.*, 2002) on use of 1/200 000 agriculture map (Boulos, 1963) and landcover map 1987 1/50 000 (FAO, 1990) and classification of Landsat TM and SPOT XS of 1998. No scale harmonization was performed for those results. Harmonizing maps especially what concerns spatial scale is compulsory for landscape spatial scale analysis.

Total forest cover describes only one dimension of ecological problems encountered at the study area. Landscape indices computations and the inside-outside patch analysis determined the entire view of forest loss and fragmentation. The exact location of major changes and the degree of severity has been investigated. These are important steps toward better management plans.

Fragmentation of forest patches was studied on patch by patch analysis and then over the landscape. These results suggest that the forests over the study area of Mount-Lebanon have reached the residual type of forests (Figure 6), identified in more than 100 locations that faced important degradations (Table 5).

Inside-outside forest patch analysis determined the patches that have faced severe fragmentations. Landscape indices calculated to the inside of the older forest patches expressed the level of degradations for each patch. Landcover transition matrix based on the limits (edge) of the 1965 forest patches was also an important output of the inside-outside patch analysis. These results together with forest regeneration investigations add to the importance of applied technique.

The exact ecological effect of such severe fragmentation remains unknown until monitoring changes on species level is performed. However, it is clear that the large fragmentation and forest loss in the area will be accompanied by enormous change on lower levels of biodiversity such as species richness and evenness. Species monitoring studies suggested that even small scale fragmentations of the forests can have adverse effect on species viability (Stevens & Husband, 1998).

Previous studies have used various sources of spatial data for landscape analysis. However, they directly resampled resolution (grain) of the maps to reach homogenous spatial scale (Boentje & Blinnikov, 2007). This algorithmic alteration of spatial data might completely deviate from reality or ground truth. The error of the results might increase dramatically. This suggested methodological analysis (inside-outside) kept the used maps in their original scale (product original spatial scale). The used landscape indices and techniques were able to define areas of major forest loss and fragmentations. Although overlaying coarse scale map on a detailed one also holds errors, it enables detailed understanding on precise forest patch location. However, it is important to use in similar studies maps that do not have very large difference in spatial scales (Echeverria *et al.,* 2006).

Forest dynamics could be investigated using thematic maps; however, carefulness must be taken concerning spatial scale and legend differences. Comparable legends of different maps acquired at various dates and for diverse purposes can be attained through semantic analysis.

Perceptions of the map authors have to be considered in details when defining new legends. Comparable spatial scale could be managed through generalization of the highest spatial resolution map to reach the coarser scale. Generalization of a map scale could be applied for definite and particular objectives, *e.g.,* ecological analysis (Hessburg *et al.,* 1999). Landcover maps comparison does not only need an algorithmic experience; it is a research process that requires field knowledge and thematic expert decision. More studies on map harmonization are needed as it is certain that most countries around the world have maps of different spatial scales and legends.

Landscape indices demonstrated to be useful tools in exploring variability of a landscape through time. They also provide valuable ecological information for the investigated site, *e.g.,* description of the forest conditions for management purpose (Cumming & Vernier, 2002).

Monitoring through remote sensing and field surveys can effectively support he analysis of fragmentation processes. However, variations in satellite image resolutions highly influence landscape pattern analysis. Data on edaphic factors and human interventions also help in forest fragmentation analysis (Krummel *et al.,* 1987; De Cola, 1989; Turner, 1989). Comprehensive analysis of landscape fragmentation is possible through overlaying additional thematic layers like urban areas, roads, mines and socio-economics, especially that climate changes can significalty amplify the fragmentation process initiated by anthropogenic activities.

This type of integrated analysis are highly required in Lebanon as restoration and conservation practices could not be engaged on a sustainable manner without better understanding of the forest fragmentation processes over the last three decades.

This paper has contributed to an ecological characterization of changes in forest resources, using different spatial data sources, and has provided important spatial information on the Mediterranean forests dynamics that are essential in future management plans.

ACKNOWLEDGEMENTS

This article is a part of a Ph.D thesis of I. Jomaa at the University Paul Sabatier-Toulouse III, supported by the National Council for Scientific Research and achieved at the Remote Sensing Center (CNRS, Lebanon).

REFERENCES

Abi Saleh, B., Nasser, N., Hanna, R., Safi, N., Safi, S. Tohmé, H. 1996. *Etude de la diversité biologique du Liban*. Ministère de l'Agriculture, Liban, PNUE, projet GF/6105-92-72, publication no. 3., pp. 146.

Baalbaki, A. 2000. *Local and sectoral development, debate on Lebanese concept and experiences.* (Arabic), Faculty of Social Science, Lebanese University, pp. 197.

Boentje, J.P., Blinnikov, M.S. 2007. Post-Soviet forest fragmentation and loss in the Green Belt around Moscow, Russia (1991–2001): a remote sensing perspective. *Landscape and Urban Planning*, in press.

Boulos, F.B. 1963. Carte agricole du Liban avec divers aspects météorologique, touristique, administratif et social. Conseil National de la Recherche Scientifique, Liban, 3ème édition, 1980.

Burel, F., Baudry, J. 2003. *Landscape ecology: concepts, methods and applications.* Technique et Documentation, Paris, Science Publishers, Inc., pp. 362.

CoDeL. 2001. *Combating desertification in Lebanon*. A joint project of GTZ (Germany) and Ministry of Agriculture (Lebanon).

Cumming, S., Vernier, P. 2002 Statistical models of landscape pattern metrics, with applications to regional scale dynamic forest simulations. *Landscape Ecology*, 17: 433-444.

De Cola, L. 1989. Fractal analysis of a classified Landsat scene. *Photogrammetric Engineering and Remote Sensing*, 55: 601– 610.

Diamond, J.M. 1975. The island dilemma: lessons of modern biogeographic studies for the design of natural reserves. *Biological conservation* 7: 129-146.

di Castri, F., Younès, T. 1995. Introduction: Biodiversity, the emergence of a new scientific field-its perspectives and constraints. *In:* di Castri, F., Younès, T. (eds). Biodiversity, science and development : towards a new partnership. Wallingford, CAB International, pp. 1-11.

Dubertret, L. 1953. Carte géologique de la Syrie et du Liban au 1/50,000^{e}. 21 feuilles avec notices explicatrices, République Libanaise, Ministère des Travaux Publics, Imprimerie Catholique, Beyrouth, 66 p.

Echeverria, C., Coomes, D., Salas, J., Rey-Benayas, J.M., Lara, A., Newton, A. 2006. Rapid deforestation and fragmentation of Chilean temperate forests. *Biological conservation,* 130: 481- 494.

El Husseini, K., Baltaxe, R. 1965. Forest type map at 1/50,000 scale. Forestry Education, Training and Research Project, Green plan, Lebanon, United Nations Special Fund/FAO.

FAO 1990. Lebanon landcover map of 1987 at scale 1/50 000. (twelve sheet).

Ferraz, S.F.B., Capão, L.M.S.A.C., Vettorazzi, C.A. 2006. Temporal scale and spatial resolution effects on Amazon forest fragmentation assessment in Rondônia. *International Journal of Remote Sensing,* 27(3): 459-472.

Forman, R.T.T., Godron, M. 1986. *Landscape Ecology,* John Wiley & Sons, New York.

Franklin, J.F. 1994. Developing information essential to policy, planning and management decision-making: The promise of GIS. *In:* V. Alaric Sample (Editor), Remote Sensing and GIS in Ecosystem Management, Island Press, Washington DC, pp. 18-24.

Gèze, B. 1956. Carte de reconnaissance des sols du Liban au 1/200,000^{e}. République Libanaise, Ministère de l'Agriculture, Direction de l'Enseignement et la Vulgarisation, Station Agronomique Libano-Française, notice explicative, 52 p.

Gustafson, E.J. 1998. Quantifying landscape spatial pattern: what is the state of art? *Ecosystems*, 1: 143-156.

Hessburg, P.F., Smith, G.B., Salter, R.B. 1999. Detecting change in forest spatial patterns from reference conditions. *Ecological Applications*, 9: 1232-1252.

Hunter, Jr. M.L. 1996. Benchmarks for managing ecosystems: are human activities natural? *Conserv. Biol.*, 10: 695–697.

Jomaa, I., Bou Kheir, R. 2003. Multitemporal unsupervised classification and NDVI to monitor land cover change in Lebanon. *Options Méditerranéennes*, Série B, (46): 43-49.

Krummel, J.R., Gardner, R.H., Sugihara, G., O'Neill, R.V., Coleman, P.R. 1987. Landscape patterns in a disturbed environment. *Oikos*, 48: 321–324.

Lauga, J., Joachim, J. 1992. Modeling the effects of forest fragmentation on certain species of forest-breeding birds. *Landscape Ecology*, 6(3): 183-193.

Leitao, A.B., Ahern, J. 2002. Applying landscape ecological concepts and metrics in sustainable landscape planning. *Landscape and Urban Planning*, 59: 65-93.

Mandlebrot, B. 1967. How long is the coast of Britain? Statistical self-similarity and fractional dimension. *Science*, 156: 636– 638.

Masri, T., Khawlie, M., Faour, G. 2002. Landcover change over the last 40 years in Lebanon. *Lebanese Science Journal*, 3(2): 17-28.

McGarigal, K., Marks, B.J. 1994. *FRAGSTATS: spatial pattern analysis program for quantifying landscape structure*. Reference manual, Forest Science Department, Oregon State University, Corvallis Oregon, 62 p.+ Append.

Mladenoff, D.J., White, M.A., Pastor, J., Crow, T.R. 1993. Comparing spatial pattern in unaltered old-growth and disturbed forest landscapes. *Ecological Applications*, 3 : 294– 306.

MoA 2002. Landcover map of Lebanon-obtained from satellite images of the year 1998 (Landsat TM 5 merged to IRS panchromatic). Prepared by the Lebanese National Council for Scientific Research (CNRS), Remote Sensing Center, with the collaboration of IAURIF (Institut d'Aménagement et d'Urbanisme de la Région d'Ile de France), LEDO program, UNDP, Ministry of Agriculture and Ministry of Environment (Lebanon).

MoA/UNEP 1996. *Etude de la biodiversité du Liban*. Ministry of Agriculture, Lebanon/UNEP, project GF/6105-92-72, report, publication no. 9.

MoE/UNEP 1998. *National biodiversity study and action plan*. Ministry of Environment. Lebanon/UNFP, biodiversity, GEF.

NFA 2005. *National forest and tree assessment and inventory*. Technical Corporation Program, Lebanon (TCP/LEB/2903) between 2003 and 2005, Ministry of Agriculture.

Nilsson, C., Grelsson, G. 1995. The fragility of ecosystems: a review. *Journal of Applied Ecology*, 32: 677-692.

Noss, R. F., Cooperrider, A.Y. 1994. *Saving nature's legacy*. Island Press, Wash. D.C., 416 pp.

O'Neill, R.V., Krummel, J.R., Gardner, R.H., Sugihara, G., DeAngelis, D.L., Milne, B.T., Turner, M.G., Zygmunt, B., Christensen, S.W., Dale, V.H, Graham, R.L. 1988. Indices of landscape pattern. *Landscape Ecology*, 1: 153-162.

Opdam, P., Van Apeldoorm, R., Schotman, A., Kalkhoson, J. 1993. Population responses to landscape fragmentations. *In:* C.C. Vos and P. Opdam, Landscape ecology of a stressed environment, Chapman Hall, Cambridge, pp. 145-171.

Plassard, J. 1971. Carte pluviométrique du Liban à l'échelle de $1/2^{00.000e}$. République Libanaise, Ministère des travaux publics, Direction Générale de l'Aviation Civile.

Reed, R.A., Johnson-Barnard, J., Baker, W.L. 1996. The contribution of roads to forest fragmentation in the Rocky Mountains. *Conservation Biology,* 10: 1098–1106.

Salleo, S., Hamze, M., Jomaa, I., Pitt, F., Nardini, S. 2002. Differential drought resistance of two Mediterranean oaks growing in the Bekaa valley (Lebanon). *Plant Bioscience*, 136(1): 91-100.

Saura, S. 2004. Effects of remote sensor spatial resolution and data aggregation on selected fragmentation indices. *Landscape Ecology,* 19: 197-209.

Stevens, S.M., Husband, T.P. 1998. The influence of edge on small mammals: evidence from the Brazilian Atlantic forest fragments. *Biological Conservation,* 85: 1-8.

Talhouk, S.N., Zurayek, R., Khury, S. 2001. Conservation of coniferous forests of Lebanon: past, present and future prospects. *Oryx,* 35(3): 206-215.

Turner, M.G. 1989. Landscape ecology: the effect of patterns on process. *Annu. Rev. Ecol. Syst*., 20: 171-191.

Wilcox, B.A., Murphy, D.D. 1985. Conservation strategy: the effects of fragmentation on extinction. *American Naturalist,* 125: 879-887.

Zhilin, L., Choi, Y.H. 2002. Topographic map generalization: association of road elimination with thematic attributes. *Cartographic Journal,* 39(2): 153-166.