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MEDITERRANEAN ECOSYSTEMS CHALLENGED BY GLOBAL CHANGES AND ANTHROPOGENIC PRESSURES: VULNERABILITY AND ADAPTIVE CAPACITY OF FORESTS IN NORTH LEBANON

Rita EL-HAJJ[1], Paolo VARESE[2], Nabil NEMER[3], Thierry TATONI[4] & Carla KHATER[1*]

[1] National Council for Scientific Research, Center for Remote Sensing, BP 11-8281, Riad el Solh. Beirut. Lebanon. E-mails: ritahajj.sa@gmail.com / ckhater@cnrs.edu.lb
[2] ECO-MED SARL, Tour Méditerranée, 13e étage, 65 avenue Jules Cantini. F-13298 Marseille cedex 20, France. E-mail: p.varese@ecomed.fr
[3] Université Saint-Esprit de Kaslik, Faculté des Sciences agronomiques et alimentaires, PO Box 446, Kaslik. Jounieh. Lebanon. E-mail: nabil.nemer@usek.edu.lb
[4] Institut Méditerranéen de Biodiversité et d'Écologie marine et continentale (IMBE), Université Aix-Marseille, UMR CNRS-IRD-Université Avignon. Campus de St-Jérôme. F-13397 Marseille Cedex 20, France. E-mail: thierry.tatoni@imbe.fr
* Corresponding author. E-mail: ckhater@cnrs.edu.lb (Carla Khater). Tel.: +961 04 409845

RÉSUMÉ.— *Écosystèmes méditerranéens menacés par les changements globaux et les pressions anthropogéniques : vulnérabilité et capacité adaptative des forêts du Nord Liban*.— Situé au confluent de trois the given threat. In other words, the incidence and the frequency of the impact are hastier than the ability of the ecosystem to recover through its inherent adaptive capacity, which makes the vulnerability of the system decidedly high (H). In the same conditions, if thecontinents, et en raison de sa topographie accidentée, sa biogéographie, sa géologie et les civilisations humaines particulières au bassin méditerranéen qui y sont établies, le Liban abrite des forêts exceptionnelles par leurs variations et caractéristiques, représentant un trait unique dans l'environnement aride de la Méditerranée orientale. Le Nord Liban compte une mosaïque de peuplements forestiers à grande richesse spécifique. Cependant, ces forêts sont soumises à diverses pressions d'origine naturelle et anthropique pesant sur leurs ressources intrinsèques. Cet article vise à estimer la capacité des forêts du Nord Liban à réagir aux changements globaux et aux pressions humaines à travers l'évaluation de la vulnérabilité de quatre formations forestières-types de la région en fonction de leur exposition, sensibilité et capacité d'adaptation à des facteurs de stress spécifiques, et en se basant sur des indicateurs/descripteurs des pressions abiotiques et des pratiques anthropiques. Les résultats illustrent une vulnérabilité relativement élevée des forêts au (sur)pâturage, aux incendies et à l'expansion urbaine et agricole. Bien que ces dernières détiennent une capacité d'adaptation élevée inhérente à leurs structures diverses, caractéristiques physiologiques et richesse en biodiversité, la fréquence rapide des impacts risque de compromettre leurs mécanismes d'adaptation et de défier leur capacité de résilience surtout en vue des changements climatiques globaux.

SUMMARY.— Located at the crossroad of three continents, in a complex context of topography, biogeography, geology and historic human settlements particular to the Mediterranean basin, Lebanon hosts very particular forests representing a unique feature in the arid environment of the Eastern Mediterranean. North Lebanon embraces several types of forest stands with high specific richness. These forests are however subject to several anthropogenic and natural threats. This paper aims at assessing their ability to cope with and adapt to global changes and human disturbances, through an evaluation of the vulnerability of four representative stands of the North forest communities as a function of exposure, sensitivity and adaptive capacity, with respect to specific indicators/descriptors related to biotic pressures and anthropogenic practices. Results illustrate a relatively high vulnerability of forests to overgrazing, fire events and increasing agricultural and urban encroachment. These stands have an important adaptive capacity inherent to their diverse structures, physiological characteristics and species richness. However, impacts are rapidly and frequently occurring in a way that will probably challenge their ability to provide a response and defy their resilience especially in view of the plodding effects of climate change.

Located at the crossroad of three continents, on the eastern shore of the Mediterranean Sea, Lebanon, extends over 10,452 km^2 mainly over a mountainous rugged territory (73 % of the total area consisting of two mountain ranges - Sattout *et al.*, 2005) and is home to 1.11 % of the world's plant species (Tohmé & Tohmé, 2007) and 2.63 % of the reptile, bird and mammal species

(MoE/UNDP/ECODIT, 2011). As a result of its biogeography, geology, topography and historic human settlements particular to the Mediterranean basin, Lebanon falls within a recognized center of plant diversity that is considered a global hotspot (Blondel & Aronson, 1999; Médail & Quézel, 1999; Myers *et al.*, 2000; Regato & Asmar, 2011), where more than 9,119 plant and animal species are identified (MoE/GEF/UNDP, 2009).

Based on the FAO Forest Resources Assessment (2010), forests cover about 137,000 ha (13 %) of the Lebanese territory. Nearly 57 % of their cover is composed of broadleaved species (primarily oaks), with coniferous stands (mainly pines, cedars, firs and junipers) contributing to about 31 %. Given the extreme variability in physiography, soils and microclimatic conditions, these forests represent a unique feature in the arid environment of the Eastern Mediterranean region (Sattout & Abboud, 2007), and are defined by altitudinal levels illustrated in the phyto-association map published by Abi Saleh & Safi (1988), in which 10 vegetation levels can be clearly distinguished with respect to altitude.

Lebanon is recognized as the cradle of many civilizations supporting intensive anthropogenic activities. These activities have imprinted its biological and physical environment including species richness, landscape as well as forests structure and composition (Sattout & Abboud, 2007). Most of Lebanon's forests are heavily utilized by man and are thus frequently severely impacted and increasingly vulnerable to human triggered actions such as urban sprawl, road network development, agricultural encroachment on forested spots, quarrying, overgrazing, overharvesting, uncontrolled logging, abusive hunting, forest fires, invasive species, pollution and soil erosion (Khater & El-Hajj, 2012; Khater *et. al.*, in press). In view of these existing pressures, current tangible climatic constraints such as long summer drought and torrential winter rainfalls are likely to exacerbate the consequences (MoE/GEF/UNDP, 2011). Forests are predicted to be deeply affected by climate change impacts in terms of vegetation boundaries, water yield and stand productivity (Darwish *et al.*, 2011).

North Lebanon is a critical and unique zone harbouring various natural ecosystems and habitats delineated by changes in types and structures caused by different patterns of natural resources' exploitation (El-Hajj & Khater, 2012). Located in North Lebanon, the Caza of Akkar, limited by the Mediterranean Sea on its western border, Hermel to the east, Syria to the north and the Bared River and district of Minieh-Dannieh to the south, extends over large areas embracing high mountains. It is one of the most deprived regions in Lebanon with high rates of illiteracy and marginality (Denno *et al.*, 2009). Designated as a national hotspot for biodiversity requiring urgent protection, Akkar is part of the National Park perimeters designated in 2004 by the SDATL (Schéma Directeur d'Aménagement du territoire du Liban) and the Council of Development and Reconstruction (CDR). It harbours the key representative forest communities of the North Lebanon governorate and is considered as the green reservoir of the area sheltering high rates of genetic, specific and ecosystemic diversity.

Forests cover 21 % of the Akkar Caza, an extent considered to be the largest continuous forest cover in Lebanon (El-Hajj & Khater, 2012). The region is a critical biodiversity area as it harbours mosaics of patches of all Lebanese forest types amongst which Turkish pine (*Pinus brutia*), oak species (*Quercus calliprinos*, *Quercus infectoria* and *Quercus cerris*), and mixed cedar (*Cedrus libani*), fir (*Abies cilicica*) and juniper species (*Juniperus excelsa*, *Juniperus drupacea* and *Juniperus foetidissima*) stands.

However, alike other forests in Lebanon, those of North Lebanon are heavily impacted by unsustainable anthropogenic practices (El-Hajj *et al.*, 2013) and are expected to experience a significant shift in bioclimatic level from sub-humid to semi-arid if climate change scenarios were to become a reality (MoE/GEF/UNDP, 2011). This will radically challenge the survival of the species and considerably affect forest stands, where *C. libani*, *A. cilicica*, *Q. cerris* and *J. excelsa* have also been identified as having the lowest natural adaptive capacity to current and future climate trends (Sattout & Nemer, 2008; MoE/GEF/UNDP, 2011).

The resilience of a forest ecosystem to changing environmental conditions and human impacts is determined by its biological and ecological resources, in particular, the diversity of the species (including micro-organisms), the genetic variability within species, the diversity of stands' structures within the forest and the regional pool of species and ecosystems (MoE/GEF/UNDP, 2011). Resilience is "the ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organization, and the capacity to adapt to stress and change" (IPCC WG2 2007:880). It is also influenced by the size of the forest (generally, the larger and less fragmented, the better) and the condition and character of the surrounding landscape (Jomaa *et al.*, 2007). Forest resilience is straightly related to its vulnerability, being defined as the risk and amplitude of impacts to which a system is susceptible to and unable to cope with (Wilson *et al.*, 2005). It is a function of the character, magnitude, rate and variation of the driver of change to which a system is exposed, its sensitivity, and its adaptive capacity (Cleveland & Morris, 2006; Malone, 2009). As per Lindner *et al.* (2010), sensitivity describes the degree to which a system is affected, either adversely or beneficially; exposure specifies the projected change that is affecting the system; impacts are the consequences that are likely to affect forest goods and services and forestry activities, as a function of exposure and sensitivity to changes; and adaptive capacity describes the ability of a system to adapt to changes. It consists of the ability of trees, forest ecosystems and social systems to react to evolving hazards and stresses so as to reduce the likelihood of their occurrence and/or the magnitude of their harmful outcomes. While adaptive capacity in the forest sector is relatively large in the Boreal and the Temperate Oceanic regions, it is most limited in the Mediterranean region where large forest areas are only extensively managed or unmanaged (Lindner *et al*., 2010). Malone (2009) confirms that vulnerability, resilience, and adaptive capacity provide together a framework which links biophysical climate sensitivity to socioeconomic factors that mitigate or amplify the consequences of environmental changes. Analysing the relationships between exposure and sensitivity to changes, as well as the adaptive capacity potential, is a crucial aspect in decision making processes regarding where to invest, who should make the investment, and when.

Based on the analysis of four representative stands of the North Governorate forest communities located in the Caza of Akkar (Karmchbat, Fnaidek, Qobayat and Andeket), this paper aims at assessing the vulnerability of the northern Lebanese forests in the face of global changes and anthropogenic pressures as a function of their exposure, sensitivity and adaptive capacity to key stress factors related to biotic pressures and anthropogenic practices. This assessment will thus provide an evaluation of the overall resilience of these stands and prioritize the main stress factors triggering increased forests' vulnerability in the Mediterranean region.

SITE DESCRIPTION

Information gathered in the following section arises from field assessments and meetings with municipalities. Fig. 1 displays the exact geographical location and boundaries of the selected forests for the study.

FOREST OF KARMCHBAT

Located at the highest peak of the upper Akkar watershed at an altitude ranging between 1400 to 2100 m, Karmchbat forest harbours stands of mixed conifer species largely grouped in bouquet structures with dominance of *Abies cilicica* and *Cedrus libani*. Slope ranges in the Karmchbat forest between 0 and 80 %. The bedrock is composed of limestone outcrops and screes on slopes, and local *terra rossa* is frequent onsite. *Juniperus excelsa* and *Juniperus foetidissima* form permanent stands in the upper altitudes and the rocky sites of the mountainous bioclimatic level. On the western slopes of the forest, *Quercus cerris* and *Quercus infectoria* are present in mixed coniferous-broadleaved stands. *Abies cilicica* reveals itself with very abundant multi-stems trees (branches are cut in summer for goats). *Quercus calliprinos* grows in Karmchbat mixed forest up to 1500 m, similarly to *Pinus brutia* in southern exposed slopes, whereas *Cedrus libani* trees grow at altitudes up to 1900-2000 m in sparse and low density populations along with *Juniperus* and *Astragalus* stands associated to *Acantholimon* shrubs. *Berberis libanotica* is commonly found on forest hedges in altitudes ranging from 1500 to 2000 m. Small number of species strictly associated to mixed coniferous forests are recognized in the herbaceous understory layer

(*Cyclamen coum, Doronicum orientale, Geranium libanoticum,* etc.*),* especially in microsites over humid rich soils under *Abies cilicica* trees. Open areas with abundant *Echinops viscosus* and other ruderal spiny species are frequent in the middle of the forest. This species is eaten by goats in spring when leaves are tender and spiny-less. About 1000 goats graze in the area of which approximately 500 are active in the forest. Topsoil erosion and overgrazing are the two main threats to the forest.

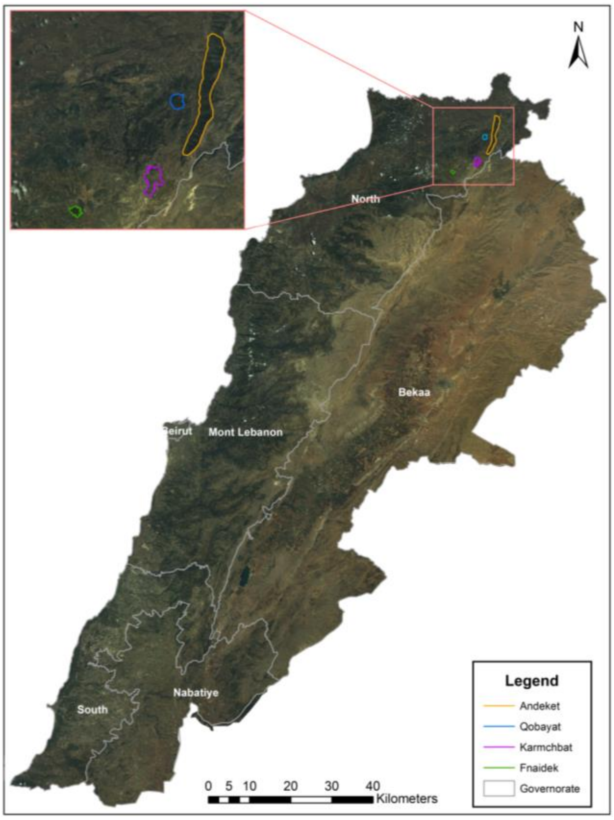

Figure 1.— Geographical location of the Karmchbat, Fnaidek, Qobayat and Andeket forests in North Lebanon.

FOREST OF FNAIDEK

Fnaidek forest is considered one of the only relic and remnant stands of *Quercus cerris* in Lebanon (Sattout, 2006). Located between 1330 and 1600 m of altitude on a limestone bedrock with *terra rossa* deep soils, and on a slope ranging between 0 and 60 %, it is represented by two Turkey oak (*Quercus cerris*) forest types: Turkey oak in mesophilous sites over clay deep soils (*terra rossa*) on flattish grounds, and Turkey oak in mesoxerophilous sites on rocky outcrops and sloped grounds, where *Juniperus* sp. pl. also forms stands on the upper rocky sites too. The mesophilous sites are characterized by the presence of mesophilous indicator species like *Doronicum orientale, Geranium libanoticum, Cyclamen coum, Geum urbanum*, whereas the mesoxerophilous sites boast "xeric" indicators species such as *Juniperus* sp. pl., *Teucrium polium, Euphorbia macroclada, Styrax officinalis, Ruscus aculeatus, Lonicera etrusca* and *Quercus calliprinos* (which sprouts are heavily browsed by goats). *Festuca heterophylla, Rubia aucheri, Pteridium aquilinum* are commonly found on all expositions, while *Berberis libanotica* is only present on the forest's borders. *Quercus cerris* is the dominant species of this forest with a relatively high presence of *Juniperus* sp. pl. and shrubs in mesoxerophilous sites. However, the potential vegetation can consist of mixed oaks/conifers woodland. Acorns and regeneration of Turkish oak are missing on the ground. Fruit production by *Q. cerris* is locally important within the forest only every 4 to 5 years.

FOREST OF QOBAYAT

Extending between 600 and 1200 m of altitude on a limestone or marlstone substrate and a slope range of 0 to 60 %, *Pinus brutia* is the dominant tree species along with local *Quercus infectoria* (in shrubby layers) in the Qobayat forest. *Pistacia palestina, Phlomis longifolia, Phillyrea media, Juniperus oxycedrus*, *Styrax officinalis*, *Rhamnus punctata*, *Cercis siliquastrum* (in mesoxerophilous sites) and *Calicotome villosa* are commonly associated species encountered within the forest. An herbaceous hedge of *Piptatherum miliaceum* is also frequent on the site's borders. Other herbaceous species such as *Smilax aspera, Rubia tenuifolia, Asparagus acutifolius* and *Clematis cirrhosa* are rare. In eastern side slopes, at an approximate altitude of 1000 m, *Quercus calliprinos* forms pure xerophilous coppices of about 3-3.5 m height. These stands were previously cut and used (20-25 years ago) for charcoal production. *Quercus calliprinos* is considered the potential vegetation specie of the Qobayat woodland, tending to densely regenerate under the pines cover and outweigh the latter due to its high tolerance to shady locations. *Pinus brutia* is a pioneer species and is stable on rocky outcrops. Within the forest, terraced and flat sites previously cultivated with corn are found. Today, these areas serve as grazing spots for shepherds, although grazing pressure within the pine forest is low comparing to a moderate status in oak stands. Other pressures such as mushrooms and aromatic plants (like *Thymbra spicata* or *Salvia* sp. pl.) harvesting are generally slight and do not affect forest dynamics.

FOREST OF ANDEKET

Pinus brutia dense stands grow in the Andeket forest (located between 400 and 700 m of altitude), even on the steepest slopes (80 %). The mountain ridge is however exempt from vegetation due to the presence of bare limestone rocks hindering trees growth.

Beneath the pine coppices, *Quercus calliprinos* develops locally stratified stands on discontinuous *terra rossa*. Pines stands are yearly exposed to forest fires in Andeket. According to Koepsell *et al.* (2012), it is important to examine the potential evolution of the forest stands. The lower and bottom slopes of the forest (at the proximity of the Oudine valley) are occupied by agricultural spaces and grasslands. Besides, stands of riverine trees like *Platanus orientalis, Nerium oleander* and *Salix* sp. pl. bind the small stream flowing into the valley.

METHODS

Aiming to assess the vulnerability of the four selected forest stands, the following methodology has been adopted:

The main stress factors on the forests were identified through:

- Onsite observations and forests' vitality assessment (assessment of existing biotic pressures, mainly pests. Only were considered insects that potentially cause damages to trees).

- Consultation meetings with local stakeholders (municipalities and communities) to highlight the key anthropogenic pressures on forests resources, and evaluate perceptible climate trends over the past decade (in terms of precipitation patterns and temperatures).

Fig. 2 illustrates the general approach for vulnerability assessment adopted in this study.

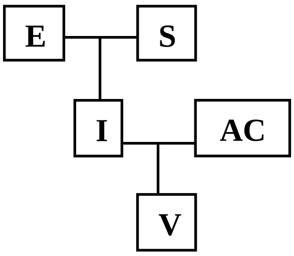

Figure 2.— General approach for vulnerability assessment (E = exposure; S = sensitivity; I =impact; AC = adaptive capacity.

The exposure (E), sensitivity (S) and adaptive capacity (AC) of every forest to each of the identified stress factors were then evaluated through expert opinion (of all co-authors) in view of onsite descriptors/indicators as shown in Tab. I.

Stakeholders' consultations were very effective in determining the exposure of the forests to stress factors. The analysis of climate trend models (from year 1950 to 2100) including projected temperatures and precipitations patterns, also provided a good indication on forests' exposure in Lebanon to climate fluctuations (MoE/GEF/UNDP, 2011).

Accordingly, the impact (I) and vulnerability (V) of the forests to each of the factors were assessed with respect to Tab. II where "L" refers to "Low", "M" to Medium and "H" to High. When a system is poorly, fairly or highly exposed (L, M or H) to a natural incident (forest fires, storms, etc.) or any given type of anthropogenic disturbance (overgrazing, logging, etc.) and retains in return a low (L) sensitivity to these incidents due to its ability to rapidly cope and adapt to the changes, the impact prompted by these stress factors is then low (L). The impact of an incident is also deemed low (L) if the system has a medium or high sensitivity (M or H) to this latter whereas it is lowly exposed to it (L). On the contrary, a system is highly impacted (H) when it is decidedly exposed (H) to an external disturbance, while it is highly sensitive to this latter (H). In the same analytical spirit and in all other cases, the crossing result of exposure and sensitivity is a Medium impact (M). On another hand, if the impact of a natural or anthropogenic incident on a forest ecosystem is low (L), it won't affect in neither way its natural dynamics nor vitality regardless from the adaptive capacity it holds (L, M or H).

TABLE I

List of onsite descriptors/indicators used for assessment of forests' exposure, sensitivity and adaptive capacity to stress factors

Stress factor	Decreased precipitation	Increased temperature	Grazing	Logging	Hunting	Agricultural and urban encroachment	Soil erosion	Forest fires	Pest attacks
Exposure	- Climate trend analysis - Meteorological data - Variations in water table level - Presence of species from lower bioclimatic levels - Local perception of stakeholders	- Climate trend analysis - Meteorological data - Presence of species from lower bioclimatic levels - Local perception of stakeholders	- Number of heads grazing in the forest and its vicinity - Grazing permanence (on a same site) and frequency - Grazing periods - Number of grazed shrubs	- Number of loggers - Logging frequency - Age of logged trees (growth rings counting) - Site accessibility - Visibility of spots from main roads (logging is illegal in Lebanon)	- Number of hunters - Number of cartridges on soil - Site accessibility - Hunting seasons - Proximity of forests to housing - Hunted species (and their relation to trees regeneration patterns)	- Number of agricultural orchards within the forest and its vicinity - Number of privately owned parcels within the forest and its vicinity - Percentage of agricultural and urban expansion per year - Land use changes over the years	- Continuity of vegetation cover - Density of vegetation cover - Soil type - Slope degree - Rainfall patterns - Grazing patterns - Logging and rock excavation activities	- Frequency of forest fires - Number of burned spots - Drought trend analysis - Frequency of recreational activities within the forest - Vegetation type and density	- Climatic variations - Density of pests per vegetation type (trapped and identified in pheromone traps) - Site's biotic and abiotic conditions - Economic injury levels of pests
Sensitivity	- Number of xeric and steppic species compared to mesophilic ones - Number of evergreen broadleaved species instead of deciduous ones	- Number of thermophilic species compared to mesophilic and cryophilic (on higher altitudes) ones - Number of evergreen broadleaved species compared to deciduous ones	- Number of regeneration of dominant / noteworthy species per m^2 - Damage level to grazed shrubs	- Number of dead trees - Type of wood	- Presence of the forest on migration flyways	- Landscape connectivity with other forests of similar type	- Soil retention capacity - Rainfall interception - Species rooting system	- Number of dead trees - Soil damage after fire - Number, type and speed of regeneration after fire - Understory density - Presence /absence of access roads	- Damage level to attacked trees - Number of dead trees
Adaptive capacity	- Northward shifting (number of regeneration of key species (cedar, fir and Juniper) on northern expositions) - Variation in stands' age (growth rings counting) - Variability of stands' structure and composition - Water retention capacity (soil type, depth, abundance of organic matter, etc.)	- Upward shifting (number of regeneration of key species (cedar, fir and Juniper) on higher altitudes) - Variation in stands' age (growth rings counting) - Variability of stands' structure and composition	- Specific richness (*alpha* diversity) - Variability of stands' structure and composition - Variation in stands' age (growth rings counting) - Vegetation density	- Variation in stands' age (growth rings counting) - Frequency of new sprouts - Forest's regeneration capacity	- Avifauna diversity, population age and community composition - Biodiversity richness (birds' attraction)	- Occurrence of open areas in the forest (caused either by grazing activities or natural windfalls) - Forest's ability to expand on non-forested lands in its vicinity	- Variability of expositions and soil characteristics (depth, texture, abundance of organic matter, etc.) - Specific richness (*alpha* diversity)	- Specific richness (*alpha* diversity) - Frequency of new sprouts after fire - Species' physiological characteristic (exploding cones of pines, resistance to fire of cedars, etc.)	- Species physiological characteristics (e.g. cedar summer buds to compensate foliage loss after attack by mites) - Species diversity and fauna balance

The system is therefore lowly vulnerable to the given stress factor (L). Nonetheless, if the impact of a disturbance is high (H), while the adaptive capacity of the forest is low (L) due to the poor ability of the ecosystem to react to the stress so as to reduce the likelihood of its occurrence and/or the magnitude of its harmful outcomes, its vulnerability is thus likely to be high (H) tothe given threat. In other words, the incidence and the frequency of the impact are hastier than the ability of the ecosystem to recover through its inherent adaptive capacity, which makes the vulnerability of the system decidedly high (H). In the same conditions, if theimpact is medium or high (M or H) but is oppositely occurring in a pace to which the ecosystem is still able to respond to due to its high adaptive capacity, the latter is then lowly vulnerable (L) to the given stress factor. In the same analytical spirit and in all other cases, the crossing result of impact and adaptive capacity is a medium vulnerability (M).

TABLE II

Impact and vulnerability assessment matrixes

Impact assessment matrix

		Exposure		
Sensitivity		L	M	H
	H	L	M	H
	M	L	M	M
	L	L	L	L

Vulnerability assessment matrix

		Impact		
Adaptive capacity		L	M	H
	H	L	L	L
	M	L	M	M
	L	L	M	H

RESULTS AND DISCUSSION

Results of the vulnerability assessments are comprehensively displayed in table III illustrating the level of exposure, sensitivity, impact, adaptive capacity and vulnerability of each forest to the identified stress factors.

VULNERABILITY AND ADAPTIVE CAPACITY OF THE KARMCHBAT FOREST

Overgrazing is the main threat to which the mixed conifer forest of Karmchbat is exposed. The forest revealed high vulnerability to grazing activities as shown in table III. Almost nil regeneration of the dominant species (*Cedrus libani* and *Abies cilicica*) was encountered. This increasing risk alters natural forest dynamics while compromising the species natural reproductive cycles. However, the high specific richness rate and habitats diversity, the heterogeneity and complexity of stands' structures, the species' possibility of shifting upwards (altitudinal migration), and the physiological tolerance of *Cedrus libani* and *Abies cilicica* to forest fire incidents, make Karmchbat more or less resilient to global changes and anthropogenic pressures (Medium overall vulnerability as illustrated in Tab. III). A potential increase of hunting activities or any eventual urban or agricultural encroachment (mainly on privately owned lands within the forest) can hamper this resilience. An important number of studies on endemic and relic coniferous species (*Pinus, Abies, Juniperus, Cedrus*) in the Mediterranean basin confirms indeed the high fragility of such populations (mostly in dry mountain areas) to overgrazing (Linares & Tiscar, 2010, 2011; Linares, 2011; Linares *et al.*, 2011; Tiscar & Linares, 2011; Candel-Perez *et al.*, 2012). This type of human disturbance increases forests' vulnerability by impeding their intrinsic resilience, which might lead to their eventual progressive demise. However, the site's topographical and geo-pedological factors as well as the stands' structural variability are key elements which increase the adaptive capacity of the species. If the forest structure is diverse (presence of juvenile and adult specimens) and the specific richness is important, adaptation chances are likely to increase. Mixed and irregular stands have a better resilience compared to homogeneous structures. Rameau (1991) confirms that at a sylvi-genetic level, the presence of a varied stock of pioneer or transitory species (pines, some particular shrubs, etc.) has an important buffer role in the face of climate change. Likewise, a dense understory also creates a more stable microclimate, crucial for the regeneration of certain species.

VULNERABILITY AND ADAPTIVE CAPACITY OF THE FNAIDEK FOREST

Similarly to Karmchbat, the Fnaidek forest is highly exposed to grazing pressure (Tab. III). New regenerations of *Quercus cerris* are nearly absent in the understory, which on its turn, is almost exempt from vegetation due to grazing intensity. Moreover, the high exposure of the forest to urban and agricultural encroachment challenges its subsistence especially that it is geographically confined in a rural setting potentially subject to expansion. It has also been reported by local residents who frequently visit the forest that fruit production by *Quercus cerris* is only observed every 4 to 5 years due to the advanced trees age, which further reduces the forest's adaptive capacity. However, the occurrence of quite steep rocky stations within the forest relatively increases its adaptive capacity in terms of providing safe microhabitats for new regenerations. The existing variability of expositions, slopes and soil depth influences water balance and availability. In case of increased temperature and decreased precipitations, the presence of mesophilous sites (northern expositions, low slopes and deep soils) compensates the rise of potential evapotranspiration and improves local species adaptation (El-Hajj *et al.*, 2013).

TABLE III

*Vulnerability matrix to stress factors of the Karmchbat (*A. cilicica/C. libani*), Fnaidek (*Q. cerris*), Qobayat (*P. brutia/Q. infectoria*) and Andeket (*P. brutia/Q. calliprinos*) forests*

	Climatic factors		Anthropogenic factors				Other		
Stress factor	Decreased precipitation	Increased temperature	Grazing	Logging	Hunting	Agriculture and urban encroachment	Soil erosion	Forest fire	Pest attacks
KARMCHBAT									
Exposure	M	M	H	M	M	L	L	L	M
Sensitivity	L	M	H	H	M	M	H	L	H
Impact	L	M	H	M	M	L	L	L	M
Adaptive capacity	M	M	L	M	L	L	M	H	M
Vulnerability	L	M	H	M	M	L	L	L	M
FNAIDEK									
Exposure	M	M	H	L	H	H	L	L	M
Sensitivity	H	H	H	H	L	H	H	M	H
Impact	M	M	H	L	L	H	L	L	M
Adaptive capacity	M	M	L	M	L	L	L	L	M
Vulnerability	M	M	H	L	L	H	L	L	M
QOBAYAT									
Exposure	M	M	M	L	L	H	L	H	M
Sensitivity	M	M	L	L	L	M	M	H	H
Impact	M	M	L	L	L	M	L	H	M
Adaptive capacity	H	H	M	H	H	L	H	L	M
Vulnerability	L	L	L	L	L	M	L	H	M
ANDEKET									
Exposure	M	M	L	L	L	M	L	H	L
Sensitivity	M	M	L	L	L	H	M	H	M
Impact	M	M	L	L	L	M	L	H	L
Adaptive capacity	H	H	M	H	H	L	H	H	M
Vulnerability	L	L	L	L	L	M	L	L	L

VULNERABILITY AND ADAPTIVE CAPACITY OF THE QOBAYAT FOREST

The high exposure of the Qobayat forest to fire risks (Tab. III) (fire events reported yearly through municipal records) threaten its survival, even though pine trees have a relatively high adaptive capacity to forest fires through the ability of efficiently regenerating/recovering after fire incidents (Tsitsoni 1997; Spanos *et al.*, 2010). However, the regular occurrence and prompt fire impacts on the Qobayat forest affects the existing ecosystem and alter its inherent functionalities, especially that the fire recurrence pace outdoes that of the reproduction period of the pine trees (2 to 3 years) and the subsequent cones production. This situation affects forest vitality, perennity and productivity in terms of wood and non-wood products, and further disturbs understory associated dynamics. The high sensitivity of the Qobayat forest to fire events (Tab. III) is mainly due to its dense understory, the absence of access roads facilitating the entry of fire extinguishing equipment, and the high occurrence of dead pine trees (combustible biomass) within the forest which potentially increases fire propagation risks. Hence, although species like *Pinus brutia* can well regenerate after forest fires (Dafis, 1987; Thanos & Marcou, 1991; Spanos *et al.*, 2000; Thanos & Daskalakou, 2000; Tsitsoni *et al.*, 2004) - pine seed germination and seedling emergence taking place during the first wet season and continuing for the following five years till saturation (Ming, 1987; Tsitsoni, 1997) - and have an important reliance on this incident for reproduction, the impact of such events can sometimes outweigh the forest's adaptive capacity, which makes it in return vulnerable to this threat. Besides, Qobayat reveals an overall low vulnerability to potential climatic variations and anthropogenic disturbances, with yet a higher vulnerability to agricultural and urban expansion risks and insect attacks (Tab. III).

VULNERABILITY AND ADAPTIVE CAPACITY OF THE ANDEKET FOREST

Globally, the Andeket forest reveals a potentially high resilience to both climatic impacts and anthropogenic pressures. Yet, at the difference of the Qobayat forest, Andeket is more exposed to agriculture encroachment risks and is therefore much vulnerable to this factor (Tab. III). Several agricultural spaces are encountered within the forest and on its selvedge. Any possible future expansion of these areas could lead to an eventual fragmentation of the pine stands. However, the presence of these zones on the bottom edge of the forest reduces fire propagation risks and is thus valuable. On another hand, similarly to the Qobayat forest, Andeket is exposed to fire risks. Nevertheless, due to its high adaptive capacity inherent to the pine trees physiology, the sparse understory, and the presence of a fairly developed dirt road network within the forest, the stand is deemed lowly vulnerable to potential fire risks (Tab. III).

The adaptation of forests' species in view of pressing changes can be strictly evaluated through dieback phenomena (Legay & Ladier, 2008). Phytopathology studies and other mycological aspects (*mycorrhizae*) in addition to insect pest outbreaks are crucial to assess to better understand the potential impacts of climatic variations on forest vitality. Hence, in terms of forest health, Karmchbat forest revealed the presence of two insects associated with the cedar tree physiology of summer buds formation: the anobiid beetle *Ernobius libanensis* (*Coleoptera*: *Anobiidae*) and the cedar cecidomyid *Dasineura cedri* (*Diptera: Cecidomyiidae*). Optimal development and reproduction of these insects occur between 20 and 25^{o}C (Nemer *et al.*, 2006). An increase in this average temperature hastens their development and rate of reproduction, particularly in the high mountainous altitudes (Nemer, 2008). Cedar trees exhibited the presence of summer buds on a large percentage of living trees (60-70 %). Summer buds development in July compensates foliage loss during winter and spring and can be considered as an adaptation property of cedar trees to pest outbreaks.

In contrast, the forests of Andeket and Qobayat showed no signs of stress associated to pest attacks. However, these two forests were previously severely attacked by the pine processionary moth *Thaumetopoea wilkinsoni* and required several aerial sprayings of diflubenzuron (selective insecticide) and *Bacillus thuringiensis* (biological pesticide) between 2001 and 2011 in order to the eradicate the insect. This fact increases the sensitivity of these forests to potential pest outbreaks.

Consultations with the municipalities of Karmchbat, Fnaidek, Qobayat and Andeket villages emphasized on further highlighting the main uses and patterns of exploitation of forests resources by local communities for income generation and sustainability of livelihoods. In all four cases, municipalities stressed on the fact that forest resources exploitation (although unsustainable in most cases), contributes to the fulfilment of several local families' substantial living needs while ensuring a decent part of their annual income. This is mainly pronounced in Karmchbat and Fnaidek with overgrazing activities that are clearly affecting forest dynamics and jeopardizing their persistence, while providing high revenues for the grazers. In Qobayat and Andeket, anthropogenic practices within the forests are quite controlled by the municipalities and active local NGOs which strive to reconcile environmental conservation principles with livelihood priorities. Yet, increasing human pressure remains unanimously recognized as the main threat to the forests, to which potential plodding effects of global changes are adding to exacerbate the consequences. Until alternative income generating activities are created in the four villages to satisfy natural resource users' needs, local communities cannot be denied from forest resources exploitation given that in such a situation, human living priorities outweigh ecological conservation priorities.

In North Lebanon, as in nearly all Lebanon, the plodding effects of global changes add to the existing anthropogenic pressures on forest resources (overgrazing, abusive wood logging, intended forest fires and uncontrolled urban sprawl) hence increasing their vulnerability (MoE/GEF/UNDP, 2011). Species like *Abies cilicica, Quercus cerris, Pinus brutia, Cedrus libani, Juniperus excelsa* and *Juniperus foetidissima* are at their southern limits of extension (Abi-Saleh, 1988) and some research results are beginning to further investigate forest dynamics and biological data in the area (Sattout, 2006; Sattout & Abboud, 2007; Jomaa *et al.*, 2007; Sattout & Nemer, 2008; SPNL/Mada, 2008; Awad, 2009) and recommend specific management perspectives (Regato & Salman, 2008; El-Hajj & Khater, 2012; Saadieh, 2011; Stephan *et al.*, 2011; Koepsell *et al.*, 2012). Yet, in a context of natural fluctuating conditions that have occurred during a long period of time, Mediterranean species have developed the ability to adapt to prevailing climatic and anthropogenic constraints. Studies from the Mediterranean region show that the current tree flora is made up of very resilient old taxa that have already experienced many abrupt and intense changes in the past, being able to maintain quite stable populations through periods where climate conditions have changed (Hajar *et al.*, 2008; Petit *et al.*, 2008). However, current global changes are occurring in a very fast pace (drastic detected temperatures increase and rainfall patterns variations), so quickly that they are putting the species biological adaptation processes at risk (Lindner *et al.*, 2010). Several studies also confirm that biological organisms are trying to adapt themselves to a quick changing environment (Lindner *et al.*, 2010). However, given the differences in interspecific genetic and physiological adaptation abilities, it remains quasi-impossible that all stands could achieve a successful adaptation in view of occurring pace of global changes and pressures. The good knowledge of prevailing ecological factors and forest stands specificities is a key step to approach forests' vulnerability (Regato & Salman, 2008; Lindner *et al.*, 2010).

CONCLUSION

As forest resilience refers to the capacity of a forest to withstand and absorb changes in the environment, adaptation implies understanding and influencing these conditions to increase forest resilience, with an overall perspective of increasing and conserving forest ecosystems services.

The vulnerability analysis of four typical forest communities of the Northern governorate deems that pine forests (*Pinus brutia*) are mainly vulnerable to forest fires while cedar and fir communities are more vulnerable to overgrazing. The Turkey oak (*Quercus cerris*) forest of Fnaidek - being a unique example of such a stand in North Lebanon - has proven on its turn to be vulnerable to overgrazing and intensive agricultural and urban encroachment. Yet, forests of North Lebanon have an important inherent ability to withstand and adapt to occurring pressures due to their high specific richness, species physiological characteristics and stands' structures variability. However, impacts are rapidly and frequently occurring in a way that will probably challenge their ability to provide a response and defy their resilience especially in view of the plodding effects of climate change.

Further investigations are needed to better understand the auto-ecology, synecology, genetic diversity and natural dynamics of species like *Abies cilicica* and *Quercus cerris*, which exhibited the lowest regeneration rates in all locations. A better evaluation of the relations between local communities and their forest resources and assessment of profits and benefits generated out of exploitation practices, would help orient adapted management for a sustainable conservation of forests in North Lebanon.

In Mediterranean developing countries (such as Lebanon), global changes should not be seen as a threat to forests but rather as an opportunity to scientists, ecosystem managers and decision makers to develop and implement measures to increase their resilience to human pressure, for in such a complex socioeconomic context and increased pressure on their resources, forests might not even survive to witness global changes impacts.

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