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Managing the environment, people and herds: sustainability of the Moroccan cedar forest

Nicolas Hamelin
School of Business Administration, Al Akhawayn University, Ifrane, Morocco, and
Sonny Nwankwo
Royal Docks Business School, University of East London, London, UK

Abstract

Purpose – The purpose of this paper is to assess the impact of human factor on ecological conditions of Moroccan cedar forest with a view to drawing out implication for sustainable forest management. The study is set against the backdrop of the global depletion of natural capital in a rare axis which, if not brought under an integrated sustainability purview, might lead to the extinction of this quickly receding natural resource.

Design/methodology/approach – Data for this research are mined from publicly held databases but processed through a time series regression analysis in a way that measures variations in ecological/environmental variables.

Findings – Findings reveal that changes in precipitation and temperature account for a small but significant amount of variation during the period 1940-2006. However, most of the decline is attributable to human activities such as overgrazing and illegal logging. These are having far-reaching implications for forest conservation management.

Originality/value – Human agency, more than any effect of nature, is chiefly responsible for the unsustainable development in this sphere of natural capital. Whilst this may not altogether constitute new knowledge, the paper highlights ambivalent positions that both promote and constrain efforts to sustain cedar forest. Its novelty lies not only in the empirical substantiation it affords but also in ferreting out strategic initiatives to dis-incentivise unsustainable exploitation of this important aspect of natural capital.

Keywords Sustainability, Sustainable development, Sustainable environment

Paper type Research paper

1. Introduction

There is continuing understanding, starting from the famous Earth Summit in 1992 through to the recent (2012) Rio Conference, that urgent actions are needed to secure core natural assets such as woodlands and biodiversity matters. Considered from a broader perspective, classical economist such as Adam Smith, David Ricardo and James Mill have long argued that land (as one of the three factors of production) could reach a "static state" where further human activity could render void much of the natural capital. In fact, of all the factors of production, land is the only immobile factor and relatively fixed. Essentially, there is an extent to which it can absorb "development" without catastrophic consequences. This makes it rather precarious; its damage as a result of unsustainable consumption may be irreversible, at least in the

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short-run. This reality is now beginning to unravel in a range of contexts. The Moroccan cedar forest is a classic example.

Cedar forest in Morocco, North Africa, occupies approximately 133,000 ha, distributed in the Middle Atlas, High Atlas, the Rif Mountains and Tazekka (Food and Agriculture Organisation (FAO) of the United Nation, 2008). In the Middle Atlas region there has been long-term decline in its area and ecological condition, with an estimate of over 40 per cent of Moroccan forest receding (Thirgood, 1984; UNCED, 1994). The decline of the cedar forest has been widely investigated, with research funded extensively by international programs such as FAO and "L'agence Française de Developpement" (El Aissi, 2008; IDRC, 2009). As a result, local forest agencies hold large data sets but the information is not centralised or readily accessible.

Recent studies have assessed the relationship between poor cedar forest regeneration and a wide range of environment variables in different regions of the Middle Atlas (Ezzahiri *et al.*, 1999; Bahmad, 1992; Bâaris, 1994). These studies have, however, mostly overlooked the human impacts. This paper assesses the data on climatic, dendrochronologic and land use variables on forest decline in the Ifrane province of the Middle Atlas region and draws out the implications for forest conservation management.

2. Study area

The region under observation is the province of Ifrane in the Middle Atlas region (Figure 1). It is subdivided into ten communes located around the town of Ifrane in the Middle Atlas. These communes, with a total population of around 143,380 inhabitants are: Azrou, Ifrane, Ain Leuh, Ben Smim, Oued Ifrane, Sidi El Mahfi, Tigrigra,

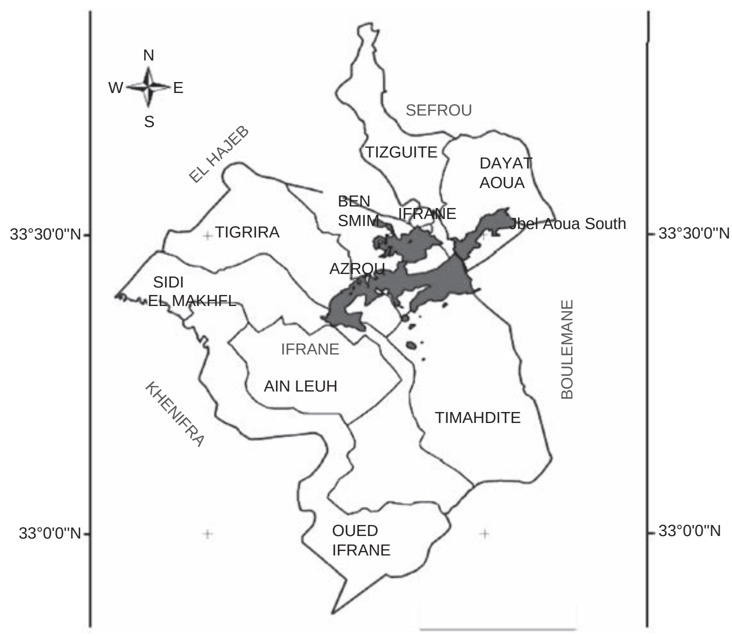

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Figure 1.
Study area: forest area – greyed on the map – with the ten communes located around the town of Ifrane in the Middle Atlas

Tihahdite, Dayet Aoua, Tizguite. They cover an area of 3,600 km^2 that encompasses most of the cedar forest of the Middle Atlas region. The forests under investigation are the forest of Azrou at the northern edge of the plateau of the Middle Atlas, a portion of the forest of Ait Youssi AmekIa and the forest of Jbel Aoua south. The forest of Azrou has an area of 17,807 ha, with 13,763 ha of forest and 4,044 ha of clearings. It is characterised by a contrasting relief with highly variable altitude. The forest of Azrou is representative of the Middle Atlas Cedar forest. (FAO of the United Nation, 2008). Atlas cedar (*Cedrus atlantica*) represents the main essence. This species is present in forest covering 8,679 ha, about 48 per cent of the total surface in pure form, together with green oak (*Quercus ilex*). The green oak forest occupies about 25 per cent of the forest cover, about 4,419 ha. The forest of Ait Youssi AmekIa under study covers over 5,737 ha with 3,113 ha of cedar and 1,384 ha of green oak. The forest of Jbel Aoua south is located in the northwest and is contiguous to the Ait Youssi amelka forest. It occupies an area of 7,865 ha and the main species are the cedar, the holm oak (*Quercus ilex*) and the maritime pine (*Pinus pinaster)* (Saar, 2011).

3. Methods

Cedar forest structure and environmental variables were reviewed or recorded to follow recent changes in forest distribution and structure. The ecological variables studied were forest area and canopy structure. The environment variables studied were climate (including changes in precipitation and temperature), physiography (including slope and altitude), soils and human impact (including forest logging, fire, grazing intensity and human population change).

Data on variables was obtained from government entities at national and regional levels. Socio-economic data were sourced from the local authorities from each of the ten communes within the province. Data for precipitation and temperature were sourced from "l" (Agence du bassin hydraulique de sebou, 2008). Data on herd composition and grazing intensity were provided from ANOC (Association for Ovine and Bovine Management, Association National des Eleveurs Ovins et Caprins, 2008) and the Ministry of Agriculture. Data on forest logging, illegal logging, grazing routes and fire frequency for the region of Jbel Aoua South were sourced from a research by El Ayres (2009). Data from satellite observation (1986 and 2004) were used to monitor the changes in forest composition and structure. Assessment of tree and forest patch decline by Landsat satellite observation and analysis was from Saar (2011). This data were available only for the region of Jbel Aoua, which spans over 7,865 ha (about 14 per cent of the province). It is, to a large extent, representative of the forest in Ifrane province in terms of forest composition and exposition to human activities. Remotely sensed aerial photography interpretation provided an understanding of the variation of tree species area and changes in tree cover composition. Dendrochronology analysis was conducted on the forests of Azrou and Ait Youssi Amekla. This area of 20,940 ha is representative of the Cedar forest for the province of Ifrane and the middle Atlas (FAO of the United Nation, 2008).

4. Results

4.1 Cedar forest area decline

Cedar forest area change data were not recorded for the entire ten-commune area since there were insufficient data to cover the entire area. Data on cedar decay was collected and assessed by using change detection techniques centred on the region of the South Jbel Aoua forest (map 1) located in the Central Middle Atlas (Saar, 2011). Cedar forest in the South Jbel Aoua region occupies an area of 7,865 ha. The main species are the Atlas cedar, holm oak and the maritime pine. Aerial photo-interpretation shows that between 1986 and 2004 the area of forest in which cedar occurs diminished (Saar, 2011) – (see Table I). There was a net decrease in the area of forest land cover in which cedar was a key satellite image component (types 1, 4, 6, 8 and 9), from 2,367 ha in 1986 to 2205 ha in 2008 (−6.9 per cent).

4.2 Climate change

A regional trend linked to global warming is the increased frequency and length of drought periods. More frequent and longer droughts have amplified tree mortality rate worldwide (Allen *et al.*, 2010). Recent extreme drought in North Africa (Touchan *et al.*, 2008) is linked to severe mortality of Atlas cedar from Morocco to Algeria (Zine El Abidine, 2003; Bentouati, 2008). Analysis of long-term climate variation shows that wet periods are necessary for the survival and expansion of the cedar and oak forest (Rhoujjati *et al.*, 2010). This has been confirmed by dendroclimatic studies which show the importance of favourable wet periods in cedar regeneration (Lamhamedi and Chbouki, 1994). More specifically Till and Guiot (1990), analysing precipitation in Morocco from 1100 AD based on *Cedrus atlantica* tree ring widths, concluded that in North Africa, the most important limiting variables to tree growth are winter and spring precipitation.

The Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change predicts that total winter precipitation in Morocco is likely to decrease by about 20 per cent by the end of the twenty-first century. This is further confirmed by the results of Driouech *et al.* (2010) who predicted that in the region of Ifrane (Middle Altas) precipitation could decline by up to 0.43 mm per day on average. They also predicted that the maximum dry spell length could increase over most of the country and especially in the regions west of the Atlas Mountains. Ayres and Lombardero (2000) suggest that climate warming may increase insect outbreaks in the boreal forest, resulting in an increase in forest fire. Similar conditions may arise in more southern higher altitude forests such as in the Middle Atlas forest range.

In the Northern Algerian region, it was observed that prolonged soil moisture deficits lead to decline and progressive death of Atlas Cedar over one to three years; mortality rate is further increased by insects such as *Thaumetopoea pityocampa and Phellinus pini*, the Mjej in the Moroccan Middle Atlas (Lamhamedi and Chbouki, 1994)

Land cover type	1986	Area (ha) 2004	1986-2004	Area (%) 1986-2004
1. *Cedrus atlantica* dominant	39	16	−23	−58
2. *Pinus pinaster* dominant	5	13	8	175
3. *Quercus ilex* dominant	3,024	3,553	539	18
4. *Q. ilex* and *C. atlantica* dominant	382	308	−75	−20
5. *P. pinaster* (dominant) and *Q. ilex*	1,164	653	−511	−44
6. *Q. ilex* (dominant) and *C. atlantica*	1,470	1,584	114	8
7. *Q. ilex* (dominant) and *P. pinaster*	519	648	129	25
8. *C. atlantica*, *Q. ilex* and *P. pinaster* dominant	391	212	−179	−46
9. *C. atlantica*, *Q. ilex* and *Quercus canariensis*	85	85	0	0
10. Reforestation with *Pinus halepensis*	34	50	16	47
11. Area of water	33	33	0	0
Total	7,145	7,154	9	1

Table I. Forest land cover area change (ha) between 1986 and 2004 for the South Jbel Aoua region and fungi aggressing weakened cedar trees (Chenchouni *et al.*, 2008). Specific to the Middle Atlas region, lack of vegetation has also pushed the local and endangered monkey, *Macaca sylvanu*, to use the cedar as subsistence food (Lamhamedi and Chbouki, 1994).

Soil moisture variation as well as soil pH variation may also have a damaging impact on Atlantic cedar seedling survival and growth. A study on Atlantic white cedar (Gengarelly and Lee, 2005) showed that soil moisture and correlated changes in soil pH are determining factors in successful Atlantic white cedar recruitment.

4.3 Temperature increase

Data for maximum and average temperature and rainfall variation have been collected over the 1958-2006 period (Ministere de L'amenagement, de l'eau et du territoir). These data have also been collected at Ifrane, located in the centre of the cedar forest. Temperature data shows a net increase in average and maximum temperature over the period 1990-2006 (Figure 2), with the highest temperature peak recorded in the summer of 2004.

Higher summer temperatures mean an increased risk of fire and increased soil moisture loss.

4.4 Decline in rainfall

A study (FAO of the United Nation, 2008) on the cedar forest around Azrou and the Ait Youssi Amekla forest, analysing the tree ring thickness as a function of rainfall, showed that there was a significant correlation between the indices of cedar growth and rainfall indices. There were waves of tree mortality during the period (1998-2003) and 2005. These years were characterised by winters with a negative water balance (1995 and 2002) or weakly positive for the winters (1997 and 2000). In 2002 the length of the growing season was limited to one month for two months compared with the

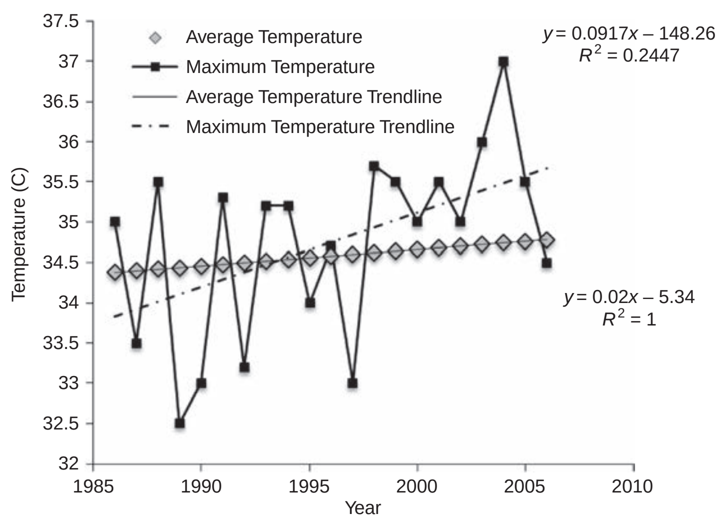


Figure 2.
Temperature variation for the Ifrane region from 1958 to 2006

Notes: Average temperature (°C) regression fit = 0.02 year – 5.34, with $R^2 = 1$; Maximum temperature regression fit (°C) = 0.0917 year – 148.26 with $R^2 = 0.24471$

year 1999. The years 1999 and 2002 also had a dry season spread over seven months and the same duration in terms of monthly water balance deficit.

There was a 21 per cent significant reduction in average precipitation between 1958 and 2006 from 1,175 to 920 mm (Figure 3). The annual rainfall in Ifrane has declined by nearly 24 per cent between 1930-1980 and 1981-2006, while the frequency of dry years has increased from 59 to 77 per cent.

4.5 Change in snow accumulation

A high percentage of the available water is accumulated as snow during the winter in the arid Mediterranean region. In Lebanon, for example, water from snowmelt contributes roughly two-thirds of the annual volume of water supplies (Shaban *et al.*, 2004).

Milder winters with reduced snow precipitation may also have an effect on Atlantic cedar regeneration and growth. Pederson *et al.* (2004) reported that tree radial growth is temperature dependent and species specific. They reported that Atlantic white-cedar and pitch pine are more sensitive to the entire winter season (December-March), whereas oak and hickory are most sensitive to January temperatures.

The Middle Atlas receives irregular snowfall in time and space during the cold season. In this area, the snow falls generally occurs from mid-autumn (November) to late winter (February) and can extend the spring (April) and exceptionally can occur in May. For the High Atlas region Boudhar *et al.* (2010) have not detected any long-term trend in snow cover variation in their seven-year (2003-2010) time series analysis of the entire High Atlas region using SPOT-VEGETATION images for mapping snow-covered areas. This seems to be in line with the data collected by Legdou (2008) from the "office national des eaux et forets". Legdou recorded snow height data for the period 1958-2006 in the Ifrane region. Linear regression analysis shows that there is a possible downward trend of snowfall depth in the recent years but the correlation was weak: $R^2 = 15.2$ per cent (Figure 4).

4.6 Cedar tree decline

Dendrochronological analysis of changes in cedar tree trunk ring width was conducted by FAO of the United Nation (2008). The study concentrated on 20,940 ha area: the forests of Azrou and Ait Youssi Amekla. This area is representative of the Cedar forest

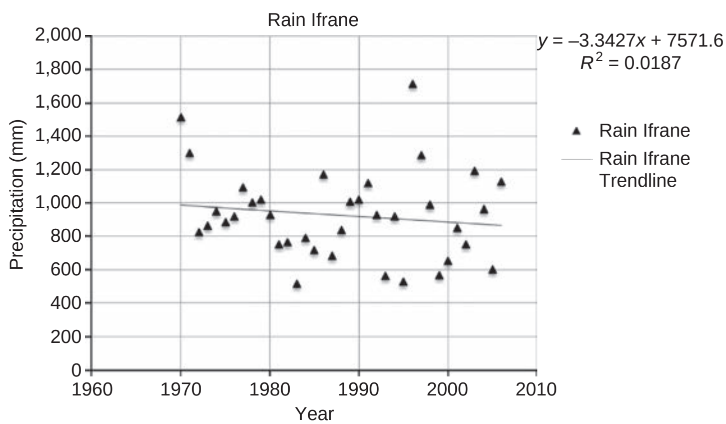


Figure 3.
Rainfall precipitation in the Ifrane region from 1958 to 2006

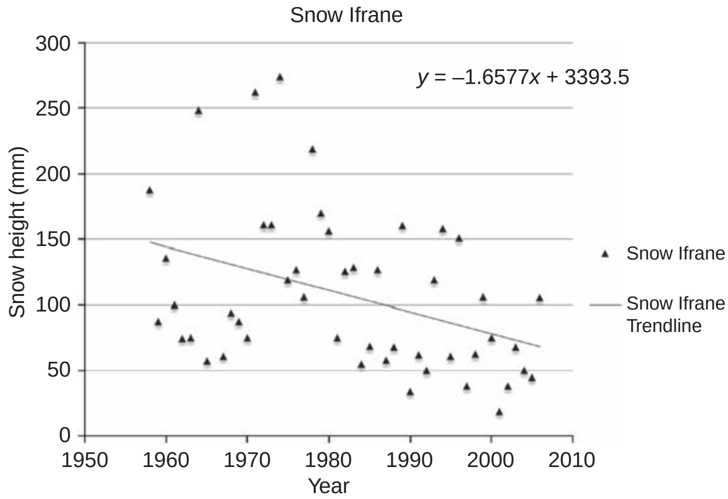
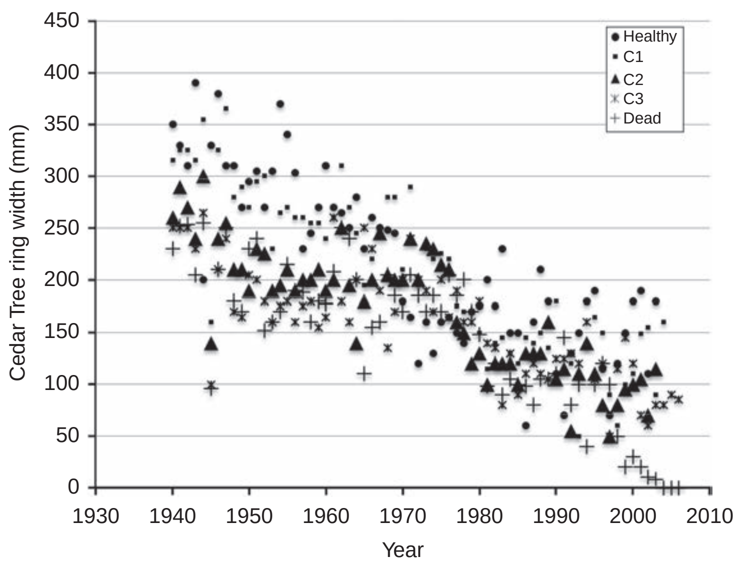


Figure 4.
Snow in the Ifrane region from 1958 to 2010

for the middle Atlas. The number of plots used for sampling was 27, recorded from 26 sites, representative of lithology, exposure altitude, slope geographical location and forest structure. Ten cedar trees were recruited from the centre of each plot, including two dead trees and two healthy trees. The sampled trees were broken down into classes of decay from healthy to dead with the following classification: C1: 1-5 per cent leaf loss, C2: 6-25 per cent leaf loss, C3: over 50 per cent of leaf losses, dead: dry crown. Cedar tree ring width was found to decline with time from 400 mm in 1940 to below 200 mm in 2003 (Figure 5).



Notes: C1: 1-5 per cent leaf loss, C2: 6 to 25 per cent leaf loss, C3: over 50 per cent of leaf losses, dead: dry crown

Figure 5.
Cedar tree trunk ring width decline with time across tree health metrics

In order to account for the decline in tree health over the period we tested the impact of the climate variables temperature, precipitation and snow depth on tree ring width during the 1940-2006 period, using a time series regression analysis in the five tree health classes. The time (t) series regression equation was expressed as:

$$Y_t(\text{Cedar tree ring width}) = \psi_{it} + \gamma_{1t}(\text{Precipitation}) + \gamma_{2t}(\text{Snow height}) + \gamma_{3t}(\text{Average temperature})$$

where t is the time variable in year.

We found no significant correlation between the climatic variables and healthy cedar tree ring width, or for tree health classes C1, C2, C3. However, for the dead cedar trees we found an F-value of 0.0006 which indicates that at 95 per cent confidence level there is a significant correlation between dead cedar tree ring width and at least one of the climatic variables. We found that mean precipitation and average temperature were both significant variables with p-values of 0.006 and 0.001, respectively. We found that mean precipitation in the Ifrane region is positively correlated to dead cedar tree ring width (Table II). This indicates that there is a positive correlation between the amount of precipitation and ring width. The low value of the correlation coefficient (0.055), indicates the explanatory effect of precipitation on tree width rate compared to the constant value of the regression (10,068) is very small. There was also a negative correlation between average temperature and cedar tree ring width. In other words higher temperature is correlated with an increase in tree deterioration. However, the explanatory effect of temperature on tree ring width is small (below 3 per cent). While climatic factors are indeed connected to the decline of the cedar forest, they are insufficient to explain the large changes in forest area.

4.7 Bio-aggressors

FAO of the United Nation (2008) identified six species of bio-aggressors affecting the cedar forest. Lichens affecting mainly stems accounted for 71 per cent of all attacks on cedars, followed by fungi, including the Mjej disease (*Phellinus chrysolloma*) accounted for 38 per cent of the attacks and 2 per cent were attributed to caterpillars. Overall, insect holes were found on 13 per cent of the stems. A total of 7.3 per cent of the trees showed damaged caused by the macaque monkey (*Macaca sylvanus*) by debarking trees and breaking top branches. Cedar was also attacked by the wood-boring insect *Phaenopsmarmottan*. It was found to be present in dead or severely damaged trees and also occurred with increasing frequency in the bark of trees in good condition. A further study conducted on the Cedar forests of the Middle and High Atlas forest of

Table II. Time series regression analysis of dead cedar tree ring width as a function of climate variables

Dead cedar tree ring width	Coefficient	SE	t	$p > t$
Number of observations = 21				
$F(3, 17) = 9.77$				
$p > F = 0.0006$				
$R^2 = 0.6329$				
Snow Ifrane	−0.1366215	0.1172849	−1.16	0.26
Rain Ifrane	0.0551892	0.0176817	3.12	0.006
Average temperature Ifrane	−290.4338	72.19167	−4.02	0.001
Constant	10,068	2,497.157	4.03	0.001

Morocco showed three main species of bio-aggressors seemed to be the most virulent: *S. numidicus*, *A. ludovicae* and *C. cedri*. It was found that these bio-aggressors mostly preyed on Cedar tree that were already degraded and were responsible for important further degradation of the tree (Benhalima, 2006). A further analysis (FAO of the United Nation, 2008) for the forest of Azrou and Aït Youssi Amekla show sporadic and negligible damage caused by phytophageous insects during the sampling period (November 2006-June 2007). However, more frequent attacks were recorded by the wood boring species, *Phaenops marmottani*. Damage was recorded for the three classes of decay (C1, C2 and C3) as well as on the dead trees (C4). Recorded damage per class C1, C2, C3 were, respectively, 3, 13 and 17 per cent (FAO of the United Nation, 2008). Whether the effect of bio-aggressors on tree health was causal or a function of climate change is not known.

4.8 Logging and grazing

The Moroccan rural population depends on firewood and charcoal for fuel (Mikesell, 1960). Recent drought has reduced the income provided from agriculture and caused the population to rely more heavily on cedar forest for subsistence. Sheep herding, logging and woodwork have increased as a consequence of the drought. Impact on the forest has been aggravated by a significant increase in the local population (Funnell and Parish, 1995). According to El Bayad (2008), total population growth between 1994 and 2004 (Table III) was 1.25 per cent per year (12.5 per cent over a ten-year period).

The Middle Atlas population is amongst the poorest in the country with an average income of 3,600 DHs (about 480 USD) compared to a country average per capita of 1,310 USD. Although the poverty rate according to estimates of the High Commission for Planning of the Government of Morocco, has declined from 16.5 per cent in 1994 to 14.2 per cent in 2004 (national average), the poverty rate in rural areas has increased from 23 to 25 per cent and unemployment is well over 60 per cent (Zouini *et al.*, 2009). Harsh winters and poverty mean that the population relies heavily on the forest for heating. There is an important deficit between the population's need for wood and forest production (Table IV). For the commune of Ain Leuh and Sefrou there are

Table III.
Population change between 1994 and 2004 for the ten communes in the study area

Commune	Population 1994	Population 2004	Rate (%)
Azrou	40,808	47,540	1.6
Ifrane	11,209	13,074	1.6
Ain Leuh	10,501	10,174	−3
Ben Smim	6,314	6,283	0.0
Oued Ifrane	9,882	11,028	1.1
Sidi El Mahfi	14,026	16,292	1.6
Tigrigra	10,838	10,849	0.0
Tihahdite	8,585	10,080	1.7
Dayet Aoua	6,868	8,699	2.6
Tizguite	8,648	9,424	0.9

Table IV.
Estimated wood production and fuel needs for the communes of Aïn Leuh and Sefrou

Commune	Wood production (tonne/year)	Estimated population needs (tonne/year)
Aïn Leuh	2,805	8,353
Sefrou	50	3,903

estimated deficits of 5,548 tonnes of wood per year, and 3,853 tonnes, respectively. These assumptions are based on an average need of 3.5 tonnes of wood per unit family of four for an average winter season. Colder winters could bring the consumption of wood to over five tonnes per family.

The lack of resources means that a majority of the population has recourse to illegal logging. Illegal logging in the Middle Atlas region mostly takes place deep in the forest so as to go unnoticed. It can be linked to the appearance of open patches in the forest canopy (Carlson and Groot, 1997). Open patch microclimate influences tree regeneration, since without the filtering effect of a canopy, cedar seedlings are exposed to a higher intensity of UVB and blue light (Lavender *et al.*, 1990; Lamhamedi, 1988).

At maturity, Atlas cedar is a medium to large tree, from 30 to 40 m tall, with a trunk diameter of 1.5-2 m. Within the tree population, large trees are essential to the forest structure and regeneration as they provide protection for seedling growth. Groeneveld *et al.* (2009), have shown the importance of structural connectivity between regenerating fragments and mature forest stands. Laurance *et al.* (2000) showed that rainforest fragmentation is responsible for increased large-tree mortality and that near edges there is an almost 40 per cent increase in big-tree mortality over the expected.

The number of registered infractions for illegal logging, labouring, cutting burning and off limit grazing reported for the 1995-2005 period (Figure 6) in the Jbel Aoua Sud region increased greatly (El Ayres, 2009). Illegal logging is by far the most frequent offence followed by off limit grazing. The data provided do not include the severity of the offence, such as the amount of wood illegally extracted or the type of wood. It is also underestimated, as small infractions are not reported. Most families will take part in some illegal logging before winter, simply because they do not have the means to purchase wood. A tonne of wood costs from 35 USD in the 1990s to 160 USD per tonne in 2011. Such prices are largely unaffordable for most of the population. Large cedar trees are also a profitable source of revenue, fetching prices from 3,000 to 5,000 USD a tree. Illegal logging is thus a lucrative business. Based on a corruption perception index (Transparency International, 2013) Morocco went from a modest rating of 4.7 in year 2000 to a worse rating of 3.7 in 2012. The country slipped from 47th place in 2000 to 88th place in 2012.

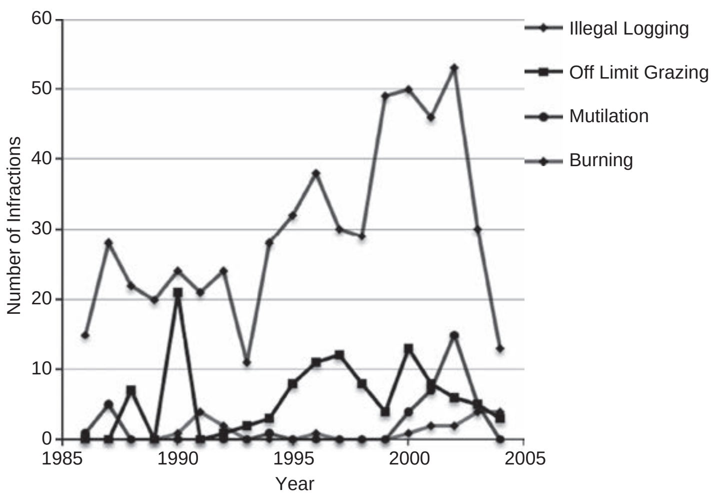


Figure 6.
Recorded infractions for illegal logging, cutting, burning, labouring and off limit grazing for the 1985-2005 period in the Jbel Aoua Sud region

Although this is the first time that a correlation between forest decay and temperature increase has been performed, most reports ignore the importance of human impacts and conclude that climate change and global temperature increase is the cause of cedar mortality. Climate change implies that very little action needs to be taken at local level. It is an argument for local government to avoid facing land use issues.

Logging leads to forest fragmentation, an important factor of the cedar forest decline. Abouelasoued (2005) has analysed cedar mortality as a function of altitude, slope, cedar density and green oak density. Using logistic regression analysis, he found that at a significance level of $p = 0.05$, cedar density is the only significant variable, with altitude, slope and green oak density having no effect on cedar mortality rate. More precisely, a negative correlation was found between cedar density and cedar mortality; i.e. the lower the cedar density the higher the cedar mortality. Comparative research on forest fragmentation in China and the USA have shown that agricultural expansion driven by an increasing and large population are the major contributors to China's forest fragmentation patterns (Li *et al.*, 2010). Although the Moroccan Middle Atlas population density cannot be compared to China, population increase in the region driving land use intensification is associated with a decline of the area of cedar forest.

4.9 Overgrazing

Over time this population increase and the introduction of goats has led to reduced tree species. There are an estimated 16 million sheep in Morocco, of which over 90 per cent are in rain fed areas (Al-Balghitti, 1994). It is estimated that over 22 per cent of the total sheep population are grazing in the Middle Atlas region (Khallaayoune, 1997).

Although sheep are no longer permitted to graze within the forest boundaries, goats are generally uncontrolled and left free to graze within the forests. In the mountainous regions of Morocco, goats are known to be a key factor in deforestation (Mikesell, 1960). Drucker (1984) evaluated the density and composition of flocks that graze in the Middle Atlas forests and the subsequent deforestation effects. A later study by Ciani *et al.* (2005), showed that only 14 per cent of the 484 km^2 area of the central region of the Middle Atlas Mountains terrain surveyed between June 1994 and October 2002 could be classified as intact, while 48 per cent presented recent signs of grazing and 38 per cent showed signs of overgrazing (degraded).

In Lebanon, Boydak (2003) has investigated the effect of heavy cutting, burning and goat grazing on the Lebanon cedar forest and maintains that the rare small forest populations that have survived are mostly located in Anatolia where the inaccessible topography of the Taurus Mountains has prevented Lebanon cedar from being extirpated. Mwendera *et al.* (1997) noted that goats in mountainous terrain exacerbate soil erosion rates and reduce seedling growth and survival rate.

Sheep and goat grazing has been identified as one greatest threat to the *C. libani* populations (Hajar *et al.*, 2010) and is a foremost factor limiting cedar forest afforestation and reforestation success in the Mediterranean region of Turkey (Boydak, 2003). Desertification in the Maghreb region is also attributed to overgrazing and encroachment of agriculture (Puigdefábregas and Mendizabal, 1998).

Ciani *et al.* (2005) have estimated the increased livestock density in the forest from 130 sheep per km^2 during their 1994-1995 expedition to 316 sheep per km^2 in their 1998-2000 expedition and from 18 goats per km^2 in 1994-1995 to 51 goat per km^2 in

1998-2000. Increase in livestock density without increase in forage availability leads to situations of overgrazing. When there is no pasturage available, the Sheppard's cut down branches to feed their flocks. Overgrazing rates of 30.9 and 52.4 per cent have been more specifically recorded for the communes of Ain Leuh and Sefrou, respectively (Table V). Although these findings are area specific they are nonetheless representative of the overgrazing issue for the entire region under observation.

In the case of the forests of Azrou and Aït Youssi Amekla, located in mountainous region, the forage availability is greatly reduced, intensifying livestock dependency on the forest. In the forest of Azrou as in all the forests of the Middle Atlas, livestock is the main source of income for local populations.

The Azrou forest is mostly exploited by the tribe of Irklaouen which flocks graze on about 82 per cent of the forest area, the tribe of Ait Mouli which use 13 per cent of this forest and the Oulad Khaoua the remaining 5 per cent the forest. It is estimated that the forest of Azrou contribute to 53 per cent of the forage need for this tribes (FAO of the United Nation, 2008). Grazing rights for the forest of Aït Youssi belongs to the tribes of the Aït Saghrouchan of Kandar and their fractions, the Al Hajjaj, Aït Daoud ou Moussa and the Aït Nâamane whose herds graze on 71 , 25 and 4 per cent of the forest, respectively. In the case of the forest of Aït Youssi the study evaluated that the overgrazing was of the order of 87 per cent.

5. Sustainable herd management

Since 2010, a large part of the cedar forest has gained protection and is now part of the Ifrane National Park which covers over 500 km^2 and incorporates a large area of the existing Atlas cedar forest (Haut Commissariat aux Eaux et Forêts et à la Lutte Contre la Désertification, 2010). Logging is no longer permitted, however, illegal logging is still the norm and grazing practices have not changed, with sheep farming being the main source of livelihood in the Middle Atlas region (Venema and Mguild, 2002). In Ethiopia, fencing experiments around land belonging to churches have showed that in fenced plots, more seeds germinated, seedling survival was higher and seedlings grew faster than in open fields, where livestock grazing had a strong negative effect on germination, seedling growth and is linked to higher tree mortality (Wassie *et al.*, 2009).

Fencing has also been investigated at Ifrane to assess the effects of sheep exclosure on cedar regeneration but was a failure due to the destruction of the fences by shepherds and the constant violation of the enclosures by sheep flocks.

In a region where the rate of unemployment is around 60 per cent and the illiteracy rate, especially among women peak at a record of 70 per cent (Moghadam, 1997) to 97 per cent (Zouini *et al.*, 2009,) logging and sheep grazing are not only essential means of survival but also part of the profound historical landscape of the Berber people of the Middle Atlas region.

Commune	Forage production	Livestock need	Overgrazing (%)
Aïn Leuh	2,562,400	3,668,200	30.9
Sefrou	1,450,400	3,006,250	52.4

Table V. Overgrazing estimate for the communes of Ain Leuh and Sefrou

If fencing against sheep grazing is to be a successful cedar regeneration management practice, providing an adequate alternative to uncontrolled cedar forest grazing as a source of income, is needed. In the western high Atlas Mountains, communities were encouraged to switch from less sustainable land uses (shifting cultivation, sheep and goat grazing, and charcoal production) to irrigated terrace agriculture, a relatively sustainable and productive land use. Mixed results were reported by different communities (Barrow and Hicham, 2000). Intensive grazing schemes have, shown greater success (Table VI). The ANOC, a sheep and goat farmers' association, launched an experimental intensive grazing plan in the Azrou region. The scheme included regrouping some of the herds and providing them with forage, thus limiting their grazing routes. Herds were also better managed in the field, with shepherd surveillance of the herd increasing from 17 to 31 per cent of the total grazing time. An increased presence of the farmer with the herd had beneficial effects on the herd productivity indicators. Parturition rate went up from 70 to 99.5 per cent, infant sheep mortality was down by 10 per cent from 15 to 4.79 per cent, adult sheep mortality was reduced from 15 to 3.5 per cent and the abortion rate went from 10 to 0 per cent. These effects gave increased income for the farmer, with a turnover per sheep up by 86 per cent from 200 Moroccan DHs per head to 372 DHs per head. It is essential to incorporate the rate of population growth as well as socio-economics and cultural need prior to establishing a pragmatic forest conservation plan (Pressey *et al.*, 1996).

6. Conclusion

Of the variables driving recent large decreases in Middle Atlas cedar forest area, climate clearly is influential but relatively small, with a decreased soil moisture status probably rendering cedar trees more susceptible to attack from insects and parasites. The main factors responsible for decline of the forest are linked to human impact, with overgrazing by sheep and illegal logging directly responsible for inhibiting cedar tree regeneration and increasing forest fragmentation.

A key issue, associated with the current, largely unsuccessful cedar forest conservation management strategy, is the economic status of the local population, whose average income is amongst the lowest in the country, with the poverty rate estimated to be 25 per cent of the population (International Fund for Agricultural Development, 2006). We, therefore, identify integrated stock production, forestry and conservation management initiatives that would give economic and biodiversity gains. They involve promoting and developing: locally intensive sheep and goat production external to the forest; forest grazing prescriptions that allow for cedar

Table VI. Sheep performance indicators for the commune of Ain Leuh and Sefrou with and without ANOC grazing plan

	Without ANOC	With ANOC 2004-2005	With ANOC 2005-2006
Parturition rate (%)	70	72	99.5
Infant sheep mortality (%)	15	4	4.8
Adult sheep morality (%)	15	3.45	3.5
Abortion (%)	10	5	0
Yearly income/head (DHs)	200	276	372

tree regeneration; sustainable timber production regimes. Linking support to local land users for these initiatives with outcomes that give improved forest ecological condition would dis-incentivise unsustainable forest exploitation.

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About the authors

Dr Nicolas Hamelin holds a PhD in Physics from Sussex University in the UK (1994), and an MSc in Environmental Management from Ulster University. He is also a qualified TV news reporter from INA, Paris. He has worked as a Research Fellow for City University of Hong Kong, the Foundation for Fundamental Research on Matter and the Energy Center of the Netherlands. In international business, he has worked at ST-Ericsson within the Nokia BU, as a Strategic Marketing Manager. Since 2007 he has been Assistant Professor of Marketing at Al Akhawayn University. In parallel Dr Hamelin is an In-country Chief Analyst for Euromonitor International, a Reviewer for Transparency International, and completing a second PhD in Business at the University of East London. Dr Nicolas Hamelin is the corresponding author and can be contacted at: n.hamelin@aui.ma

Professor Sonny Nwankwo is Director of the Noon Centre for Equality and Diversity in Business at the University of East London.