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Cross Section Characteristics and Age Estimation of *Juniperus procera* Trees in the Natural Forests of Saudi Arabia

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Saudi Arabia is generally an arid country with a few exceptional sub-humidregions on the southwestern highlands. The southwestern highlands constitute one of the most fascinating and unusual ecoregions in the country with its natural forests. The main tree species prevailing in these forests is *Juniperus procera* Hochst. ex Endl. This species as well as other tree species are suffering an evident degradation due to different factors. Silvicultural practices are badly needed in order to rehabilitate the natural forests in Saudi Arabia. In this regard examining cross section characteristics and estimating the age of trees will offer the opportunity to obtain information about age, growth rates, and yield of these trees and to study the relation between tree growth and environmental factors. The results of the present investigation revealed that investigation of the disks from all sample trees showed that they had irregular shape and eccentric growth rings due to a lean form of the stem. Heartwood of *Juniperus procera* is purple red while sapwood is creamy white and they are clearly differentiated from each other with growth rings of both are distinct. Heartwood occupies the majority of the cross section surface at tree breast base (77.6%) while sapwood represented by only a narrow area (22%). So that the ratio of sapwood to heartwood accounted by about 28. Heart rot was seen in some of sampled trees. The estimate age of juniper trees in Taif ranged between 56 and 132 years with an average of 83 years while it was between 54 and 137 years with an average of 99 years in Baha region. Finally, the age of juniper trees in Asir region ranged between 52 and 142 years old with an average of 99.3 years.

Key words: *Juniperus procera*, Cross section, Heartwood, Sapwood, Heart rot, age.

The natural forests of Saudi Arabia are located in the southwestern mountainous area that extended from Taif in the north to northeast Jazan in the south. The southwestern mountainous region of Saudi Arabia is characterized by semi-arid climate which is suitable for the growth of certain non-xerophytic trees and shrubs. The natural forests of the southwestern region of Saudi Arabia have been offering many benefits and services for the locals and the region as a whole. *Juniperus procera* Hochst. ex Endl. is the most prominent component of the natural forests of Saudi Arabia (El-Juhany 2009). It represents approximately 95 per cent of the tree species grown in these forests (Abo-Hasan *et al.*1984). The Main uses of *Juniperus procera* wood include house construction, fence posts, poles, flooring, and wooden structures exposed to the weather where durability is required, for example beehives, and pencils.

Unfortunately, the forests are suffering from degradation represented by poor regeneration among the main tree species, spreading of die-back on juniper trees, and abandonment of the agricultural terrace systems and this degradation may be attributed to different factors (El-Juhany 2009). In order to stop this degradation and start in the rehabilitation and restoration of the damaged

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ecosystems, silvicultural practices and sustainable management must be adopted as tools of such actions.

Therefore, examination of the annual growth rings of a tree will reveal not only its age, but also the fluctuating climatic conditions during its lifetime (English Heritage 2004). Tree-ring analysis offers the opportunity to obtain information about age, growth rates, and yield of trees and to study the relation between tree growth and environmental factors such as climate (Sass-Klaassen *et al*. 2008).

Estimating the age of the trees

General introduction and technical definitions

Counting the annual rings (also called growth rings) is of the simplest ways to estimate the age of the trees, where it is known that timber trees grow in diameter by adding a new ring of wood under the bark directly every year.

Growth rings are formed depending on the growing season. In temperate regions, there is a fast growth rate in the spring decreased by the end of summer. So that the wood elements that are formed in the beginning of the growing season called early wood (the light part of the annual ring) and have large cells with thin walls. While those are formed by the end of summer called late wood (the dark part of the annual ring) and have cells with small diameters and thick walls. This property can be used to calculate the age of a tree by counting the annual rings (each ring represents one year in temperate zones). The rings may be annual if there is only one cycle of wet and dry seasons per year (Couralet *et al*. 2005; Sass-Klaassen *et al*. 2008a). Ages of tree species growing in temperate zones can usually be determined by counting annual rings on stem cross-sections or increment cores (DeBell *et al*. 1978). However, this method is not foolproof though. Some environmental conditions can cause the tree grow more than once during a growing season, and thus produce false rings; ring counts do not always indicate the tree's true age (The Biology Corner 2014).

False rings (multiple rings within a single year) may be formed, especially when growth has been checked prematurely (*e.g*., by drought) and then has resumed within the same growing season (Zimmermann and Brown 1971). False rings are wholly included within the boundaries of true rings. False ring often lead to overestimate of tree age (Panshin and de Zeeuw 1980). They arise for various reasons related to the start and stop mechanisms within a tree controlling initiation and duration of cambial activities such as pest defoliation, major wet and dry soil fluctuations, multiple flushing of preset shoots, periods of major sprout release and growth, fire or wind-damaged foliage regeneration, juvenile trees, and sub-growing-season duration crown disturbance / stress impacts (Coder 1999).

On the other hand, discontinuous rings are those appear when some of the growth increments may be interrupted; *i. e*. they do not completely surround the stem but are present in a part of it. They result when the cambium remains dormant at one or more places throughout its circumference during a current growth season, meanwhile functioning more or less normally elsewhere (Panshin and de Zeeuw 1980).

Estimating the age of the trees in the natural forests in the southwest of Saudi Arabia

Estimating the age of the trees in the natural forests in the southwest of Saudi Arabia was done for only juniper trees because of their dominancy in these forests. The current work is an approximate estimation for the age of juniper trees as it was conducted on discs from a few number of the trees cut due to the difficulty of estimate the ages of the trees through using the increment borer to collect samples of tree trunks (the wood is very hard) and to avoid cutting a large number of trees. On the other hand, as species of *Juniperus* are known to be difficult subjects for dendrochronology, regarding dating and cross-matching problems, whole trunk sections rather than cores are required for satisfactory chronology development (Sigl *et al*. 2006). Many authors mentioned that juniper species are known to be problematic for dendro-chronological studies (Conway *et al*. 1997; Esper 2000; Bräuning 2001; Sigl*et al*. 2006).

MATERIALS AND METHODS

First: the selection of sites

A number of sub-regions within the main areas of forest inventory were selected to estimate the age of juniper trees which are as follows (Fig. 1):

(A) Taif: Thaqif, Balharith and Bani Malik

(B) Baha: South and Central Baha

(C) Asir: Balqarn and El-Namas

In the selected sub-regions, several sites have been identified represent the dominant tree cover in those areas and represent the average overall shape of the trees in terms of diameter and height, and thus is expected to be closer in age to the average age of the trees in these areas.

Second: choosing trees

General observations of the growth of trees in the forests of the selected sites were recorded, then one of the largest trees from the general apparent shape; *i. e*. of the largest diameter and height categories, with trunk free from defects, especially at breast height was cut. The number of trees that were cut varied according to the expansion of each sub-region. So that six trees were cut from Taif and Baha forests at a rate of three from each, while six trees were cut from the forests of Asir sub-region.

Notes on the growth and status of the chosen tree were recorded then the diameter was measured at breast height level in two perpendicular directions. The tree was cut down using a chain saw at 10 cm high from the ground level. After felling the tree, its total height to the nearest length of 10 cm was measured.

Third: cut wood samples

A cylindrical portion(disc) with height of about 15 cm represents across-section of the tree was cut from the trunk of each fallen tree at breast height (140 cm), so that it was free of branching defects and insect and fungal infections. This disk was witted with water and wrapped with moistened cloth and put it inside a plastic refrigerators (iceboxes) are preset for this purpose, taking into account there-hydration whenever there is a need for it. The aim of the process of hydration was to prevent cracks within the sample which produces from the growth of the internal tensile stresses during sample dryness. After the completion of felling all the trees in all locations, samples were shipped to the laboratories of Wood Technology of the Department of Plant Production in the Faculty of Food and Agriculture Science, King Saud University where the wood disks (samples) were kept in refrigerator until the time of preparing them for the process of counting the annual rings.

Fourth: the preparation and processing of wood samples (discs)

The wood samples that were taken from the selected juniper trees to estimate their age in the different forests were taking out from the refrigerator at a rate of two samples every two days (Fig. 2). Then, each sample was cleaned and washed with water and left to the next morning to partially dry, so it was taken to the carpentry workshop where it was cut in the transverse direction once again to settle the cross-section of the disc and soften its texture. The samples were returned once again to the lab, where they subjected to the process of smoothing their surfaces with automated and manuals paper and glass slides, so that the annual rings look so perfectly clear when the counting stars process.

Fifth:the process of counting the growth (annual) rings

Due to their distinct color, the boundaries of sapwood/heartwood were very clear on the cross sections of *Juniperus procera* so that the areas of both were measured manually using a planimeter. A strong moving light source was prepared for the process of counting the rings. The sample was placed on a stable surface and the light source was directed to focus on its surface, in addition to preparing some magnifying lenses(10X) installed on metal stand, as well as a binocular with magnification larger than that of the lenses to clarify the vision for conducting of the count.

The process of counting the growth rings was done on the transverse direction of the tree, starting from the firstring adjacent to the center of the disc, and even the latest one in sap wood adjacent to the bark. The counting was carried out for the complete rings only, where the false and discontinuing rings were not included in the counting, with a special mark was put on the surface of the disk at the end of each five rings to facilitate and control the process of counting.

Sixth:data collection and tabulation

All the collected date were put in special forms prepared in advance (per tree) include the field data such as: name of the region and sub-region, the name of the site,the status of the growth of the trees on the site as well as the status of the tree in terms of morphology. Data of measuring tree diameter at breast height out side bark and total tree high were recorded. The last set of data that was recorded was the age of the tree.

RESULTS AND DISCUSSION

The ages of juniper trees were estimated in samples of trees were taken from three areas of the whole region of natural forests in the southwestern part of Saudi Arabia. Those are: Taif, Baha and Asir. The assessment process took place on the cross sections of the sample trees through describing its features and counting the growth rings. A stem cross-section provides the complete radial growth series of a tree (Bakker 2005).

Heartwood of *Juniperus procera* is purple red while sapwood is creamy white or whitish and they are clearly differentiated from each other. The growth rings of both heartwood and sapwood are distinct. Similarly, Sigl*et al*. (2006) found that trees of *Juniperus procera* in the Asir Mountains have clear rings which can be dated. In the present investigation, heartwood occupies the majority of the cross section surface at tree breast height (77.6%) while sapwood represented by only a narrow area (22%). So that the ratio of sapwood to heartwood accounted by about 28. The quantitative ratio of heartwood to sapwood in tree stems depends first of all on the age of trees, climatic and soil conditions, the height at which the analyzed stem cross section is located, and the crown size (Duda and Pazdrowski 1975; Nawrot *et al*. 2008). Investigation of the disks from all sample trees showed that they had irregular shape and eccentric growth rings due to a lean form of the stem. Deviation from the circular shape of stem may cause a loss of raw material in industry and errors in calculating stem volumes and information about changes in wood quality and properties (Fallah *et al*. 2012). This deviation may be due to compression wood (Warensjö and Rune 2004), tree lean, slope and wind direction (Kellogg and Barber

Table 1. Specifications and estimated age of *Juniperus procera* trees in the inventory areas of the natural forest in the south western Saudi Arabia

Tree no.	Sub-region and location	The status of forest health	Growth status of the cut tree	Tree height (m tree^{-1})	Tree diameter (cm tree^{-1})	Approximate age of tree (year tree^{-1})
Taif region						
1	Thaquif	Moderate	Irregular, 90% dead	3.80	22.5-34 (28.3)	132
2	Balhareth: Mesan	Good	Dwarfish	3.70	22-30(26)	61
3	Bani Malik: Haddad	Moderate	Poor growth	3.50	24-33 (28.5)	56
Baha region						
4	South Baha: Al-Heliah	Good	90% dieback	7.50	33-35(34)	137
5	Centeral Baha: Shahba: Sad El-Hareer	Good	Declined, 80% dead	3.80	17-18 (17.5)	54
6	Centeral Baha: Shahba (Behind Baha University)	Degraded	Declined, 80% dead	8.30	18-23 (20.50)	106
Asir region						
7	Balqarn: North Sabt El-Alaya: at the right side of Taif-Abha Road	Degraded	40% dieback	7.50	25-31 (28)	142
8	Balqarn: North Sabt El-Alaya: at the left side of Taif-Abha Road	Moderate	40% dieback	7.60	34.5-37 (35.8)	111
9	El-Namas: South Bani Amro: the entrance of Wadi Ali	Good	Good, 30% dieback	8.50	30-31 (30.5)	119
10	El-Namas: on the left side of Taif-Abha Road	Good	Irregular, 30% dieback	8.00	24-28 (26)	80
11	Balqarn: near the entrance of Sabt El-Alaya City	Good	20% dieback	7.50	17.5-20 (18.8)	92
12	Balqarn: Al-Salamah	Degraded	10% dieback	4.50	20-21	52

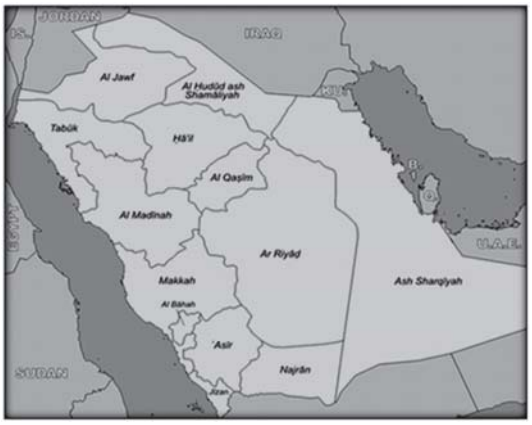

Fig. 1. Administrative regions of the Kingdom of Saudi Arabia

Fig. 2. A cross section in a disc of *Juniperus procera* tree trunk from the natural forests in the southwest region of Saudi Arabia with distinct growth rings

1981). El-Juhany *et al*. (2008) attributed the existence of irregular and deteriorated trees in the Raydah Reserve in Asir region, Saudi Arabia to various factors such as the mechanical effects of wind, soil erosion, competition between trees, animal grazing and others.

Heart rot was seen in some of sampled trees. The occurrence of fungus *Antrodia juniperina* on *Juniperus procera* has been reported (Gezahgne 2010). Older *Juniperus procera* trees are susceptible to heart rot fungus(Dale and Greenway 1961 *c. f.* Gezahgne 2010;Orwa et *al*. 2009).

The wood of *Juniperus procera* tree has a distinct but not irritating aromatic odor and it has become more fragrance when the wood is newly cut. The *Juniperus procera* wood is very fragrant, with a characteristic and persistent aromatic cedar smell (Fern 2014). Essential oil distilled mainly from the sawdust of *Juniperus procera* wood (Cedar wood oil or Cedar oil) and used in the cosmetic industry in soaps and perfumes (Couralet and Bakamwesiga 2008).

Table (1) shows that the estimate age of juniper trees in Taif area ranged between 56 and 132 years with an average of 83 years. In Baha region, it was found that the age of the trees ranged between 54 and 137 years old with an average of 99 years. Finally, the age of juniper trees in Asir region ranged between 52 and 142 years old with an average of 99.3 years. Sigl *et al*. (2006) reported an average age ranges from 51 years at Tallan Mountain South to 138 years at Soudah (the distance between Tallan Mountain and Soudah Mountain is about 140 km). They found that the maximum number of tree-rings counted were 260. Calculates the average age of juniper trees in the natural forests of south-western region of the kingdom as a whole was found to be about 95.3 years. However, there may be trees with older ages, especially in isolated areas far from the known roads and residential communities.

In every area of those from which sample trees were taken for estimating the age of juniper trees, we noticed that there only a few number of the older trees in one site if any. El-Juhany and Aref (2013a) mentioned that the present status of Taif forests suggests that they have been exploited for a long period of time, as obvious effects on the existing trees can be seen right now. They considered disappearing most of larger trees as one of the indications of the degradation of Taif forests.

Unfortunately, the area of forestland in the southwest Saudi Arabia has a long history of over exploitation and degradation (El-Juhany 2009). This situation is the same in all the areas of the region. The causes of this degradation have been reported by El-Juhany (2009). The degradation may start on the vegetation cover when significant areas of this cover are affected by one or more of biotic or abiotic factors. The decrease in the quality of site conditions related to one or a number of different forest ecosystem components

(vegetation layer, fauna, soil, *etc*.) is also count as an introduction to site degradation. Once any of these components is subjected to degradation, the whole site may eventually degrade.

Characteristics of tree cover in Taif

The present status of Taif forests suggests that they have been exploited for a long period of time, as obvious effects one existing trees can be seen right now. Although these trees probably represent the third generation, however they look irregular (curved, twisted, cleft, multi-stemmed, dwarfish and leaning) or degraded (destroyed, cut, fully cut and burned) or stricken by dieback or completely dead (El-Juhany and Aref 2013a). Abo-Hasan *et al*. (1984) mentioned that the percentage of the irregular trees in north and south Mendaq (includes a part of Taif forests) is considered high, in addition to the presence of some aged trees which their wood has decayed as they had been subjected to heart rot fungal disease as a result of being neglected and do not exploit for long time. Those trees are structurally weaker and prone to breakage. So it is difficult to estimate the size of such trees and they are not suitable for the production of wood. Abo Hasan *et al*. (1984) mentioned that the number of irregular trees is large while that of the straight stems is significantly less. They attributed this situation to the misuse of these forests through over cutting and random grazing. On the other hand, dieback of trees represents the main problem affecting the forest of Saudi Arabia. El-Juhany *et al*. (2008a) mentioned that die-back of *Juniperus procera* trees is a phenomenon has occurred since about 30 years in the southwestern forests of Saudi Arabia and affecting other tree species, however, yet there is no a single reason has been accused in this problem. The inventory of Taif forests show that there is about 5% of the total number of juniper trees are suffering from dieback at different degrees (Department of Natural Resources 2007).

It is worth mentioning that the degradation of the natural forests in the southwestern region of Saudi Arabia is not limited to a specific species, but occurred on all the tree species in these forests. The number of degraded (unmeasured) trees seems to be related to the accessibility to the sites and the effectiveness of its required protection. Whenever the forest is located in a steep site with no access roads, it cannot be accessible to man. Aged trees are vulnerable to deterioration by biotic and abiotic (non-living) factors. These include wind, water, temperature, or soil type or texture (Boa 2003), while biotic factors (opposite of abiotic factors) include living organisms influencing the environment such as pests and diseases.

The estimated age of the juniper trees in Taif forests in the present study showed that the age ranged between 56 years in Bani Malik and 132 years in Thaquif with an average of 83 years.

Characteristics of tree cover in Baha

El-Juhany and Aref (2013b) asserted that the forests of Baha look degraded in general terms of the low density of tree cover, increase the numbers of irregular trees, degraded trees, dieback and totally dead trees. Only 20% of juniper trees in Baha and Baljurashy are characterized by their straight trunks that are free of natural defects (Abo Hasan *et al*. 1984). Moreover, the results of the last forest inventory (Department of Natural Resources 2007) showed that the juniper trees which are affected by dieback represent 14.5% of the total juniper trees measured in the whole Baha forests, while the percentage of the affected trees in Central Baha and South Bah where the sample trees were fallen was 36 and 24.7%, respectively (El-Juhany and Aref 2013b). 34 cm was the largest mean stem diameter of the sample trees that were taken to carry out the present study. Those trees were virtually declined in a manner reflects the fact that aged trees in those forests are vulnerable to deterioration.

Characteristics of tree cover in Asir

Asir region occupies the bulk of Al-Sarawat Mountain range in southwestern Saudi Arabia, where its northern border begins from the southern border of Baha region and its southern borders end at the northern border of Jazan region. Asir region includes large tracts of land stretching across the eastern slopes of these mountains to the borders of the Empty Quarter and across its western slopes until the Red Sea coast(El-Juhany and Aref 2013c).

The status of trees in Asir forests suggests that they have been exploiting since long time as obvious effects on existing trees can be clearly seen right now. The main threats for these forests can be summarized as low capacity of natural regeneration of the main forest species,

die-back and die-off of trees, spread of forest fires, wood cutting, grazing, insects break out and spread of recreation areas (El-Juhany and Aref 2013c). Unmeasured trees (irregular, degraded, stricken by dieback and completely dead) represent 15.2% of the total number of trees counted in the whole Asir and East Jazan inventory area.

Such a decline may suggest that the forest had been heavily exploited or severely subjected to pests. There is a large number of trees that are either irregular or cull trees in Asir region (El-Osta 1983). El-Juhany *et al*. (2008a) attributed the existence of irregular and deteriorated juniper trees in Ridah Reserve at Asir Mountains to various factors such as the mechanical effects of wind, soil erosion, competition between trees, animal grazing and others. About 30% of unmeasured trees in Asir and East Jazan are affected by dieback and 26.4% are totally dead.

However, before 30 years Abo Hasan *et al*. (1984) found that a large proportion of the trees in Asir region is good quality juniper ones and attributed this to the relatively high rain fall and the deep soil. The sample trees that were cut from Asir forests for conducting the present investigation seem healthier than those of both Taif and Baha forests.

Examining the cross sections of the cut trees showed that the wood of *Juniperus procera* has narrow growth rings. Because juniper wood is characterized by its slow growth, this is reflected in the growth increment; the formed growth rings are usually very narrow (El-Osta and Abo Hasan 2001). It is also has many false and discontinuous growth rings. The formation of growth rings in juniper can be highly irregular and asymmetric (Wils *et al*. 2010a).

Sigl *et al*. (2006) who have done dendro climatic investigations in Asir Mountains – Saudi Arabia mentioned that juniper trees tend to grow irregularly and the amount of locally absent rings was high with difficult cross-matching between trees because of the occasional formation in juniper wood of a second, relatively narrow growth ring in a single year. They asserted that more difficulty was found due to the high incidence of intra-annual boundaries (false rings), which are thought to be built during extreme climate events like droughts.

The presence of a lot of false and discontinuous growth rings due to the prevailing climatic conditions in the region, where there is no boundary between the different seasons of the year. The climatic conditions are substantially variable within each season, which is reflected on the type of grow thrings formed (El-Osta and Abo Hasan 2001). This seems true as the growth rings are formed in response to the alternation of wet and dry seasons (Conway *et al*. 1998). But intra-seasonal anomalies in weather conditions can prevent the formation of distinct rings (Wils *et al*. 2009). If seasonality in climate is less pronounced, *J. procera* trees tend to form indistinct ring boundaries and/or multiple rings per year (Jacoby 1989; Wils *et al*. 2009). However, the existence of such growth rings does not significantly affect the quality of the wood (El-Osta and Abo Hasan 2001).

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