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Identification of the most preferred topographic elevation characteristics for the wild olive trees in Al-Baha Region, Saudi Arabia

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ABSTRACT

The aim of this research was to identify the topographical elevation characteristics most preferred by wild olive trees in the Al-Baha region. This study successfully identified the elevation preferred by wild olives. The results show that the majority (81.6%) of wild olives are located at an elevation range of 1,750–2,500m. However, in the Al-Mandaq sub-region, many wild olive trees can also be found at a lower elevation of 1,250–1,500m, while wild olive presence at a higher elevation of 2000–2,500m can be found in the Al-Baha sub-region. It was observed that at a lower elevation of 1500–1750m, most wild olive crown sizes are small, indicating that the wild olive prefers a higher elevation to grow well. These findings can be regarded as theoretically indicating landforms suitable for olive plantation. As a basis for the suitability of olive plantation sites, these topographical characteristics factors are the essential prerequisites. However, it is obvious that site suitability is subject to the temporal dynamics of environmental variables.

1. Introduction

Olea oleaster, the wild olive, has been considered by various botanists to be a valid species and a subspecies of the cultivated olive tree, *Olea europea*, which is a tree with multiple origins (Besnard and Bervillé, 2000) that was domesticated, it now appears, at various places during the fourth and third millennia BCE, in selections drawn from varying local populations (Besnard et al., 2001).

Today, as a result of natural hybridization and the very ancient domestication and extensive cultivation of the olive throughout the Mediterranean Basin, wild-looking feral forms of olive, called "*oleasters*", constitute a complex of populations, potentially ranging from feral forms to the wild olive (Lumaret et al., 2004).

The wild olive is a tree of the maquis shrubland, which is partly the result of the long presence of mankind. The drought-tolerant sclerophyllous wild olive tree is believed to have originated in the Mediterranean Basin. It still provides the hardy and disease-resistant rootstock on which cultivated olive varieties are grafted (Breton et al., 2006).

Meanwhile, the wild olive is also reported to be native to North America- an evergreen tree that reaches 20 feet with a 10-15-foot spread. This small tree is very rarely found and is reportedly even close to extinction. The olive-like, white fruits that are produced have a sweet flesh relished by birds and other wildlife and, although edible to man, should not be eaten in large quantities. However, in the United States of America, another olive tree species known as the Russian olive (*Elaeagnus angustifolia* L.) was considered as an exotic invasive weed. This thorny shrub or tree originated from South-eastern Europe and Western Asia and was reported by Katz and Shafroth (2003) as intentionally introduced and planted in the United States for windbreaks, erosion control, wildlife habitat, and other horticultural purposes. This tree was then observed to have adapted well to semiarid and saline environments. Early in the 20th century, the Russian olive escaped cultivation and spread, particularly into the large, moist riparian environments of the arid or semiarid regions of the western United States, (Stannard et al., 2002).

1.1. Mapping wild olive using remote sensing

Traditional methods (such as field surveys, literature reviews, map interpretation, and collateral and ancillary data analyses) have not been effective

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in acquiring mass vegetation covers because they are time-consuming, data lag, and often too expensive. Meanwhile, remote sensing offers a practical and economical means to study vegetation cover changes, especially over large areas.

Because of the potential capacity for systematic observations at various scales, remote sensing technology extends possible data archives from the present time to over several decades ago. Using this advantage, inventory and enormous efforts have been made by researchers and application specialists to delineate vegetation cover from the local scale to the global scale by applying remote sensing imagery.

Since then, there have been numerous efforts both regionally and nationally to map wild olives using remote sensing. One example is a pilot project initiated to develop a cost-effective method for mapping the Russian olive from scanned large-scale aerial photographs. This study area was established along a riparian zone within a semiarid region of the Fishlake National Forest, located in central Utah. Two scales of natural color aerial photographs (1:4000 and 1:12000) were evaluated as part of the project. Feature Analyst, an extension of the ArcGIS software, and several image processing software packages were used to map the invasive trees. Overall, Feature Analyst successfully located the Russian olive (RO) using the imagery with a relatively high degree of accuracy. For the map derived from the 1:4000-scale photographs, the software correctly located the tree in 85 percent of all 4-by-4 meter transect cells where the Russian olive was actually present.

However, smaller trees were sometimes missed, and the size of trees and groups of trees were frequently underestimated. The map derived from the 1:4000-scale photographs was only slightly more accurate than the map derived from the 1:12000-scale photographs, suggesting that smaller-scale photography may be adequate for mapping the Russian olive (Hamilton et al., 2006).

Another attempt was conducted in Australia to test the ability of remote sensing imagery to map olive groves and their attributes. This aimed to (a) discriminate olives varieties, and (b) detect and interpret within-field spatial variability. Using high spatial resolution (2.8m) via QuickBird multispectral imagery acquired over Yallamundi (southeast Queensland) on 24 December 2003, both visual interpretation and statistical (divergence) measures were employed to discriminate olive varieties. Similarly, the detection and interpretation of within-field spatial variability was conducted on enhanced false color composite imagery and was confirmed by the use of statistical methods.

The results showed that the two olive varieties (i.e. Kalamata and Frantoio) can be visually differentiated and mapped on the enhanced image based on texture. The spectral signature plots showed little difference in the mean spectral reflectance values, indicating that the two varieties have very low spectral separability.

1.2. Extent and distribution of wild olive trees in the Al-Baha Region

The information extracted from the Pleiades satellite image revealed that from 1,991km of the study area, only 817km (41%) indicates the presence of wild olive trees. The sub-region with the most extensive area with wild olive trees is Al-Qura, covering 270km^2, followed by Baljurashi at 192km^2 and Al-Mandaq at 150km^2. Automatic enumeration was done on the Pleiades satellite image, estimating 717,894 trees (with a crown diameter bigger than 1.5m) and thus equalling an average of 360 trees per km^2. Regarding wild olive tree density, the Al-Mandaq district ranks highest, with 613 trees per km^2, followed by Al-Baha with 563 trees per km^2. Meanwhile, the Al-Aqiq district has the lowest wild olive tree density, with only 22 trees per km^2, followed by Al-Qura with 222 trees per km^2.

From the maps shown in Fig. 1, it can be observed that the wildest olive-dense areas are located in north-eastern Al-Mandaq, south-western Baljurashi, and the boundaries of Al-Baha.

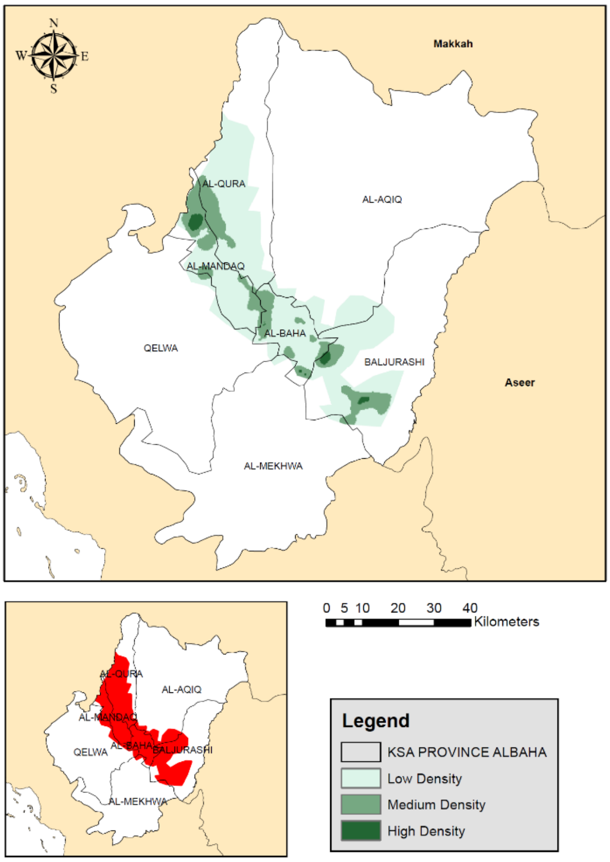

Fig. 1: Density of wild olive trees in the study area (Al-Ghamdi, 2020b)

1.3. Extent of wild olive tree presence according to the crown diameter size

The crown diameter of each tree was directly and automatically measured from the Pleiades satellite imagery. Three diameter size categories were established: Small (1.5–2.5m), medium (2.5–3.5m), and big (>3.5m). A crown diameter size smaller than

1.5m could not be easily discriminated from the image and was hence not enumerated, thus underestimating the tree count in this study. The measurement indicates that most of the trees have a small crown diameter, with 392,908 trees representing 54.7% of the total wild olive trees, and only 13.4% have a big crown diameter. It was also observed that big crown trees and medium crown trees are mostly located at Al-Qura, Al-Mandaq, Al-Baha, and Baljurashi. However, Al-Mandaq, with the wildest olive trees, has a high percentage of small crown trees-36.7% or 144,376 trees. Lower wild olive density districts such as Al-Aqiq, Al-Mekhwa, and Al-Qelwa have more trees with small crowns (Fig. 2).

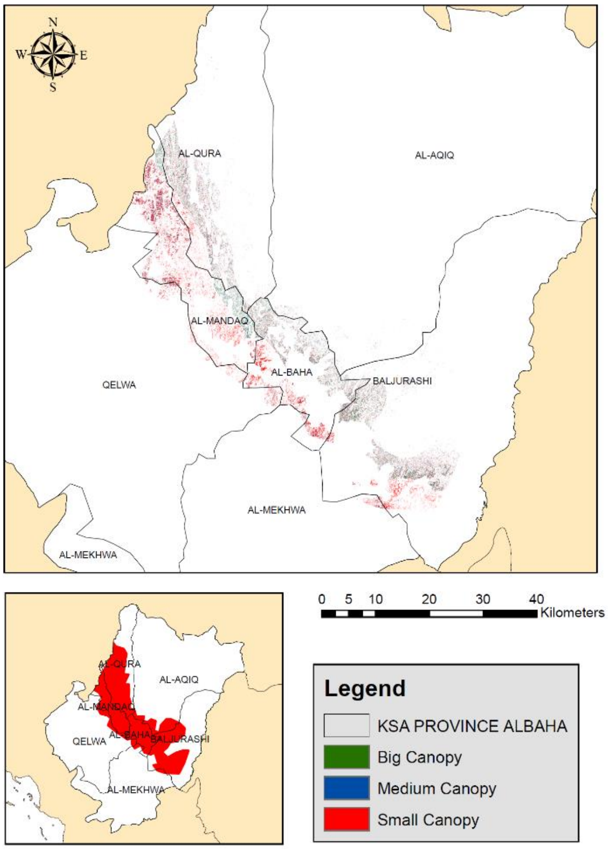

Fig. 2: Distribution of wild olive trees according to crown diameter (Al-Ghamdi, 2020c)

1.4. Extent of wild olive trees according to neighboring species

In the second phase of the project, neighboring species were automatically determined by classification using the ERDAS software and by enumerating the trees within 5 meters around the wild olive trees using the ArcGIS software. The Pleiades satellite imagery was used to determine the wild olive trees, juniper, acacia, and other species. It was found that the main neighboring species of the wild olive are juniper (40.2%) and acacia (36%), with other species comprising 23.8%. Juniper is the most common neighbor of wild olives in Al-Mandaq (32.2%) and Al-Baha (29.4%), while acacia is the main neighbor of wild olives in Al-Baha (28.3%) and Baljurashi (29.6%). The abundance of juniper trees in the Al-Mandaq and Al-Baha districts can be probably attributed to their higher elevation and the rugged nature of their mountains (especially before the introduction of modern roads), which have protected the forests there from extensive exploitation and prevented easy access to the area. Meanwhile, the small size of the trees and irregular growth show that they have been cut in the past, and the branches growing from them as coppices are considered the current trees (Fig. 3).

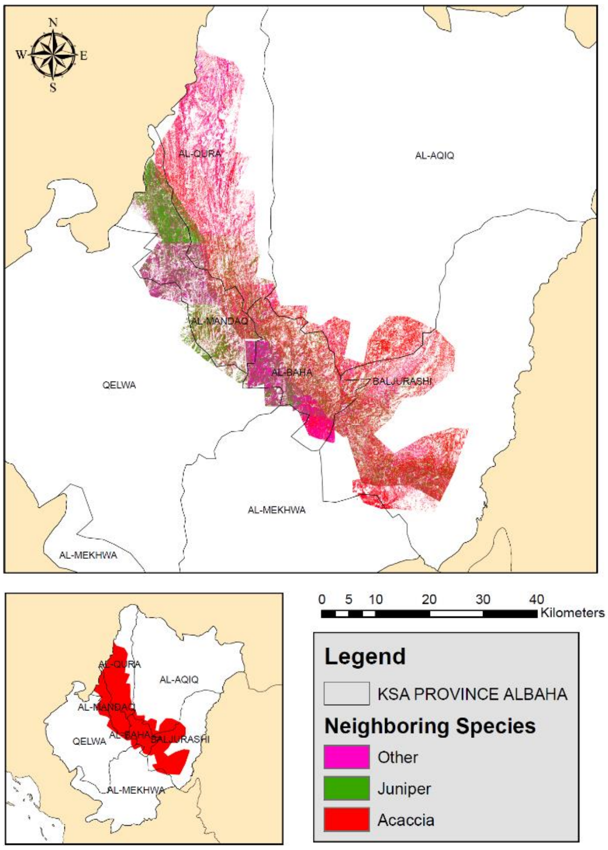

Fig. 3: Distribution of wild olive trees according to neighboring species (Al-Ghamdi, 2020d)

1.5. Vegetation: Topographical preference

The study of plant communities is the best way to learn about habit, habitat, niche, and vegetation structure (Khan et al., 2016) as well as various interactions among the plants in an ecosystem. The variation in the composition of plant species along altitude and latitude is a well-established phenomenon (Kitayama, 1992; Lieberman et al., 1985; Shaheen et al., 2012), and one of the major factors that affect the restrictions on plant species and community types in mountainous regions (Khan et al., 2011). Furthermore, the soil is an environmental factor that also determines plant growth, which is influenced by organisms, climate, topography, time, and parent material (Hoveizeh, 1997).

Climate is affected by topographical factors, such as slope, elevation, and aspect, in addition to the effect of evapotranspiration and temperature that, as a whole, result in rich vegetation in the northern aspects as compared to southern ones (Ordóñez et al., 2009). Plant species restricted by origins to specific habitats can be reached in that particular habitat due to the presence of optimum topographical factors (slope, elevation, aspect, and river proximity) as well as biotic and abiotic factors, which clearly show those plant communities and vegetation composition change along with these factors from point to point. Topographical attributes provide significant information for the categorization of different vegetation classes.

Topographical heterogeneity strongly affects other types of landscape heterogeneity, such as variation in mesoclimate, natural disturbances, soil conditions, or intensity of human impact. The main effect of landscape-scale topographical heterogeneity on local (microsite) species' richness can be seen in the control of the spatial configuration of habitats surrounding the target site. In a topographically homogeneous landscape, a site's neighborhood usually contains the same or similar habitats, while in a heterogeneous landscape, very different habitats may be found close to the target site (Zelený et al., 2010).

Observations revealed that species ranges are shifting, contracting, expanding, and fragmenting in response to global environmental changes (Chen et al., 2011).

The emergence of global-scale bioinformatic databases has provided new opportunities for analyzing species occurrence data in support of conservation efforts (Jetz et al., 2012). This has paved the way for more systematic and evidence-based conservation approaches (Margules and Pressey, 2000; Sutherland et al., 2004). However, records of observed species occurrence typically provide information on only a subset of the sites occupied by a species (Rondinini et al., 2005). Moreover, these do not provide information on sites that have not been surveyed or those that may be colonized in the future following climate change or biological invasions (Thuiller et al., 2005; Baxter and Possingham, 2011; Giljohann et al., 2011).

Nevertheless, this information is important for making robust conservation management decisions and can be provided via predictions of species occurrences derived from environmental suitability models that combine biological records with spatial environmental data. Species distribution models (SDM), also commonly referred to as ecological niche models (ENM), are currently the main tools used to derive spatially explicit predictions of environmental suitability for a species.

1.6. Geographical and topographical pattern concepts

Both geographical and topographical ecology is concerned with understanding spatial patterns to understand the process, and process to understand the patterns. Geographical and topographical ecology introduce fundamental questions on the concepts of scale, space, and place (Turner et al., 2001).

A major difference between the two disciplines is that topographical ecology focuses solely on ecological processes, whereas geographical ecology encompasses all systems, including human, ecological, biological, and physical. Ultimately, geographical and topographical ecology is concerned with broad-scale environmental issues and helps provide insights into studies of ecological systems that operate over various scales.

For example, the ecosystem provided and maintained by bees is inherently related to geographical and topographical ecology because of the importance of the spatial scale and spatial pattern in the bees' habitat. Bee distribution is geographic in nature because it is limited by climate, topography, soils, and vegetation types (Michener, 2000). Thousands of species of bees exist on our planet, and their distributions are limited by spatial variables, creating great regional diversity in bee populations.

Topographical ecology is also important for understanding bee populations because of the discipline's focus on broad spatial scales and the ecological effects of the spatial patterning of ecosystems (Turner et al., 2001). One theory common to topographical ecology and important to the conceptualization of this research is the percolation theory, which addresses the spatial pattern in random assembly. The applications of the percolation theory have brought to light questions regarding the size, shape, and connectivity of habitats (Turner et al., 2001). The percolation theory has offered considerable insight into the nature of connectivity or the inverse fragmentation of topographical features (Gardner et al., 1991).

Information on wild olive trees and suitable conditions for their growth in the forests is still limited. Thus, a complete understanding of the topographical characteristics preferred by wild olive trees has yet to be achieved. Using remote sensing and geographic information system, local people can now trace the exact locations of wild olive trees and manage a planned future area to develop olive plantations with these established topographical characteristics as compared to other olive plantation topographical areas.

It has been observed that wild olive trees are more resistant to diseases compared to normal olive plantation trees. Once affected, diseases are more easily spread in a normal olive plantation than in wild olive trees. Hence, it is essential to determine the factors that contribute to this variation in wild olive trees, especially in a disease-prone situation. This can be due to weather conditions, such as rainfall, temperature, and humidity, or topographical conditions, such as elevation, slope, aspect, river, and proximity.

1.7. The study area

According to Price (2004), the most effective way to map plant species ranges in an area is by demarcating a general bioclimatic envelope within biogeographic regions in which a species is known to have been found. Hence, this study requires building a database of species that includes data on the distribution of species by geographic region, major habitat type, and elevation range. Furthermore, in this project, due to the large area of study and to save time, cost, and energy, only areas with high potential of wild olive tree presence—indicated by high (61.8km²) and medium (790.7km²) density vegetated areas-were included in the first phase (Table 1; Fig. 4; Al-Ghamdi, 2020a).

Table 1: The study area according to district

District		Area	
Name	km²	km²	(%)
Al-Qura	1,049	586	55.9
Al-Aqiq	3,667	165	4.5
Al-Mandaq	361	339	94
Al-Mekhwa	1,949	27	1.4
Al-Baha	298	287	96.4
Baljurashi	1,505	506	33.6
Qelwa	2,232	81	3.6
TOTAL	11, 060	1,991	18

Additional search areas were also expanded to nearby lower vegetation density areas based on the neighborhood's similar characteristics. This area expanded to the northern part but not to the southern part because the southern part, i.e. Al-Mekhwa and Qelwa, consists of a steep slope tending towards lower elevation. The overall study area, which totaled around 1991km² (Fig. 4), makes up only 18.0%of the entire Al-Baha region.

1.8. Objectives

This study aims to identify the topographical characteristics (elevation) most preferred by wild olive trees in the Al-Baha region, which will act as a knowledge base for a better understanding of the occurrence and morphology of this olive species.

Moreover, the study will establish knowledge about the location and preferred topographical characteristics of wild olive trees in the Al Bahah region, Saudi Arabia.

2. Materials and methods

The main data source for the location of wild olive trees in the study area was provided from a previous study (Al-Ghamdi, 2020a). These distribution coordinates were then overlaid with topographical parameters derived from ASTER data to identify the most preferred topographical characteristics (elevation) of wild olive trees in the Al-Baha region. The following sections delineate the methods applied in this study.

2.1. Materials and data

In this study, the geospatial software used are as follows:

- ERDAS Imagine 2014: An image processing software
- ArcGIS ver 10.3: A Geographic Information System (GIS) software to conduct spatial analysis
- ArcScene: An extension of ArcGIS software used to process and display 3D images

Meanwhile, the data used in this project are as follows:

- ASTER Global Digital Elevation Model (GDEM): Used to generate elevation, slope, aspect, and rivers.
- Digital boundary of the Al-Baha region and its districts.

2.2. Methods

In this study, three main activities were conducted: Data collection involving satellite data procurement, data collection and analysis, and fieldwork. The overall workflow of this study is shown in Fig. 5.

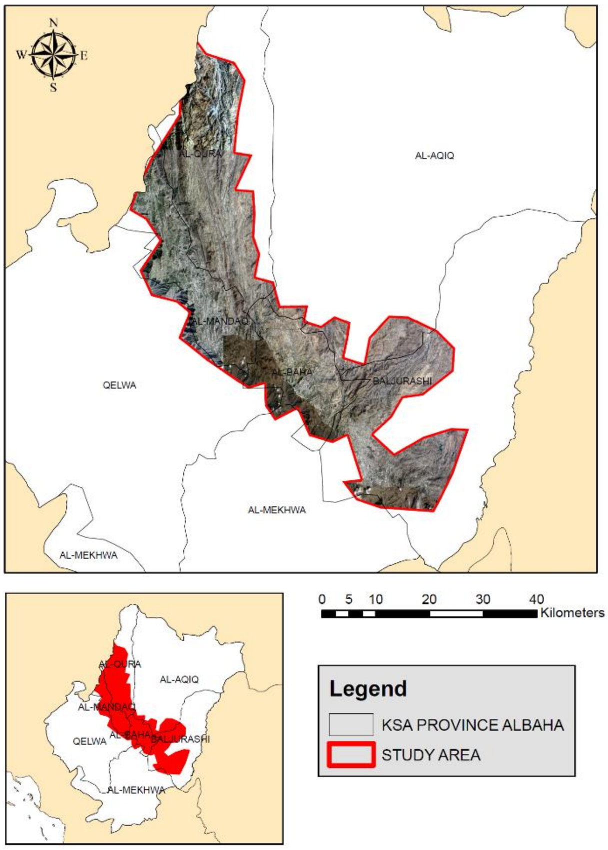

Fig. 4: Pleiades satellite image showing the extent of the study

LANDSAT-8 satellite images dated May 2016 were used as the primary source for extracting the data for this study and identifying the vegetated area in the Al-Baha region. Upon downloading from the USGS website, the LANDSAT-8 image was processed using normalized differential vegetation indices (NDVI) to demarcate areas with vegetation or chlorophyll. A workflow of the activities is shown in detail in the next section.

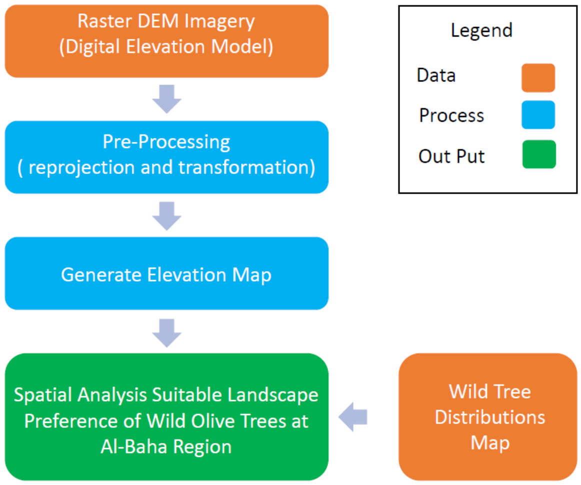

Fig. 5: Activities flowchart for wild olives topographical preference

2.3. Digital elevation model

Digital elevation model (DEM) is often used as a generic term for digital surface models (DSMs) and digital terrain models (DTMs) and only represent height information without any further definition of the surface. Other definitions consider the terms DEM and DTM as equivalent or define the DEM as a subset of DTM, which also represents other morphological elements. There are also definitions that consider the terms DEM and DSM as interchangeable. On the web, definitions that describe DEM as a regularly spaced GRID and DTM as a three-dimensional model (TIN) can be found. All datasets that are captured with satellites, airplanes, or other flying platforms are originally DSMs (such as SRTM or the ASTER GDEM). It is possible to compute a DTM from high-resolution DSM datasets with complex algorithms (Li et al., 2004). In the following paragraph, the term DEM is used as a generic term for DSMs and DTMs.

In this study, the topographical map (elevation) was acquired from advanced space borne thermal emission and reflection radiometer (ASTER) images, which is a Japanese sensor onboard the Terra satellite that was launched into the Earth's orbit by NASA in 1999. The instrument has been collecting data since February 2000. ASTER provides high-resolution images of planet Earth in 14 different bands of the electromagnetic spectrum, ranging from visible to thermal infrared light. The resolution of images ranges between 15–90 meters. ASTER data are used to create detailed maps of the surface temperature of land, emissivity, reflectance, and elevation.

ASTER topographical isoline contours consist of 5-m intervals that were eventually generated into GIS. Prior to that, the contour lines were assigned an attribute value according to their height in meters above sea level. The resulting dataset was then used to produce a DEM using ArcScene software with the 3D extension analyst. Height value was added to the existing contour line previously used in generating the DEM.

The resulting dataset was then used to overlay the wild olive tree points. Subsequently, these layers were overlaid with a tree-point layer for spatial data analysis. The last output from the spatial analysis is the suitable topographical (elevation) preference of wild olive trees.

2.4. Topographic characteristic measurement

Many topographic components are considered to highly affect wild olive tree presence; in this study, we study elevation. Meanwhile, the wild olive characteristics investigated to associate with the topographic/landform features are crown canopy size, neighboring species, and distribution. These characteristics were overlaid with the elevation topographic components to identify their association. The elevation was generated by the ArcGIS software. In this project, the elevation was divided into nine (9) elevation classes (m), as shown below:

1. 500–750 m
2. 751–1000 m
3. 1001–1250 m
4. 1251–1500 m
5. 1501–1750 m
6. 1751–2000 m
7. 2001–2250 m
8. 2251–2500 m
9. >2501 m

3. Results

Elevation criteria are deemed to contribute to the formulation of a habitat suitability index for wild olive trees. The topographical layers were categorized into several classes to quantify their variation. Subsequently, these layers were overlaid with the wild olive distribution layer to analyze the pattern. The results of this exercise are presented in the subsequent sections. The elevation classes were then displayed and overlaid with the wild olive trees point layer to determine the point of contact between the trees and the elevation map. In this study, the elevation degree was generated using Raster World DEM from the United States Geological Survey (USGS). Using ArcScene modules from ArcGIS, nine classes of elevation were categorized: (i) 500–750m, (ii) 751–1000m, (iii) 1001–1250m, (iv) 1251–1500m, (v) 1501–1750m, (vi) 1751–2000m, (vii) 2001–2250m, (viii) 2251–2500m, and (ix)>2501m. These classes of elevation were then displayed and overlaid with the wild olive tree point layer (Fig. 6 and Fig. 7) to determine where they intersected.

From Table 2, it can be observed that the majority (88.7%) of wild olive trees in the study area were at an elevation range of 1,750–2,500m. A close-up of the wild olive distribution on the elevation map is shown in Fig. 7.

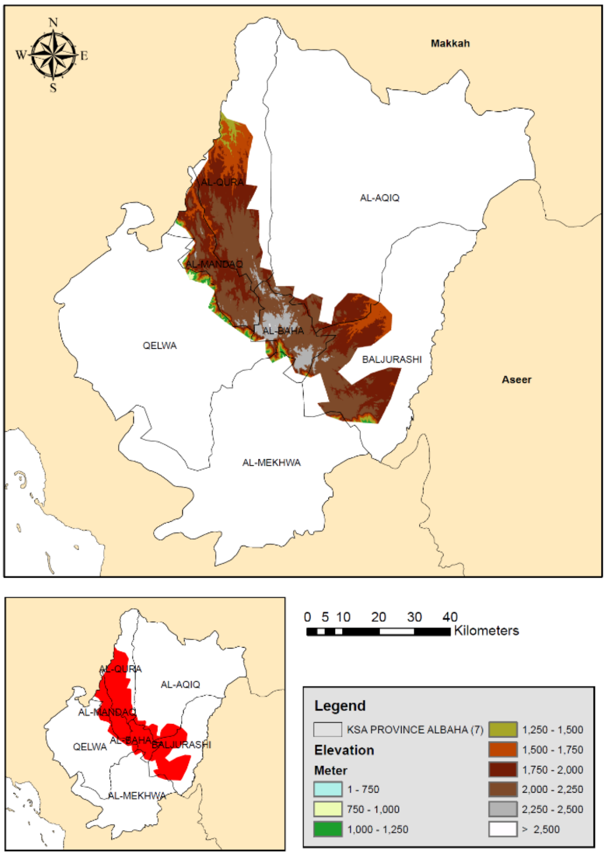

Fig. 6: Elevation map of the study area

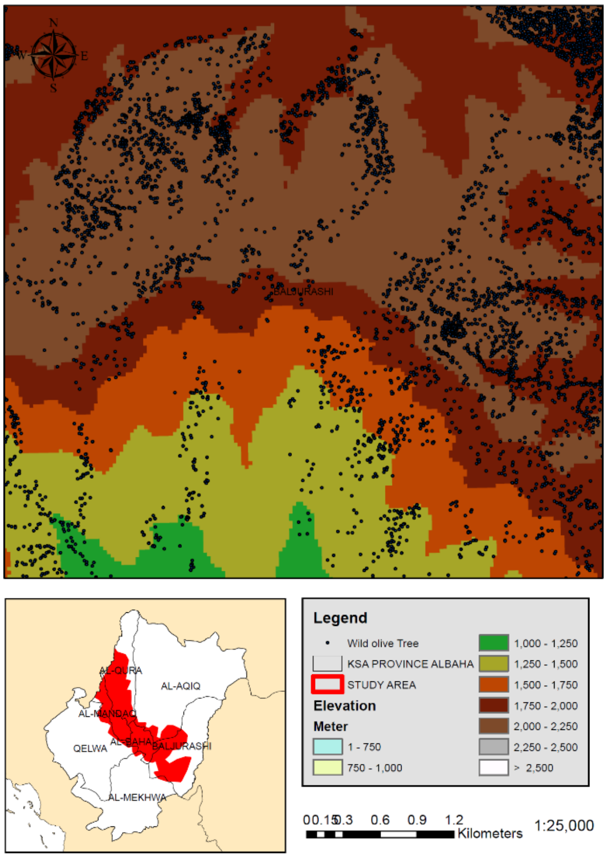

Fig. 7: Close-up view of the wild olive distribution on the elevation map

Table 2: Wild olive distribution based on elevation

Elevation code	Meter (m)	Olive tree	(%)
1	500–750	270	0.0
2	751–1000	212	0.0
3	1001–1250	3554	0.5
4	1251–1500	20,612	2.9
5	1501–1750	56,868	7.9
6	1751–2000	266,844	37.2
7	2001–2250	319,017	44.4
8	2251–2500	50,473	7.0
9	> 2501	526	0.1
	Total	717,894	100.0

Highlighted parts are where most wild olive trees found (>10%)

3.1. Extent of wild olive by elevation according to district

As shown in Table 3, most (88.7%) wild olive trees in the study area were located at an elevation range of 1,750–2,250m. However, in the Al-Baha district, wild olives were mostly found at higher elevations of 2000–2,500m, indicating that being a more developed district, many wild olives in Al-Baha at lower elevations had been cut for development in the past, leaving only the ones at higher elevations. Al-Mandaq had wild olive in abundance even at lower elevations, such as 1,500–1,750m, probably due to its steep, undulating slope at this elevation level, which did not favor development in the past. A similar pattern is also observed at Qelwa and Al-Mekhwab. However, at this elevation level, the slope is probably and relatively not too steep as compared to higher elevations.

3.2. Extent of wild olive crown diameter size by elevation

Table 4 shows that most medium and big crown trees are found at elevation ranges of 1,750–2,250m, while most small crown trees with a wider range also cover elevations as low as 1500m. This indicates that wild olive trees prefer an elevation range of 1,750–2,250m, where a lower or higher range results in trees with small crowns. Significantly, the histogram pattern in Fig. 8 shows that wild olive trees are mostly found at an elevation range of 1,750–2,250m.

3.3. Extent of wild olive neighboring species by elevation

Similar to Table 5, shows that the neighboring species of wild olives also mostly prefer an elevation range of 1,750–2,250m, except for juniper, which is also found in abundance in 1,500–1,750m. This indicates that juniper is a more versatile species that can thrive at both lower and upper elevations. Similar to the wild olive crown size pattern, the histogram in Fig. 9 clearly shows that wild olive trees' neighboring species are also mostly found at an elevation range of 1,750–2,250.

Table 3: Wild olive distribution relation with elevation according to district

Elevation (meter)	Wild olive Density														Total	
	Al-Qura		Al-Mandaq		Al-Baha		Bajurashi		Qelwa		Al-Mekhwah		Al-Aqiq			
	Tree	%	Tree	%	Tree	%	Tree	%	Tree	%	Tree	%	Tree	%	Tree	%
500-750	0	0.00	0	0.00	0	0.00	0	0.00	270	1.12	0	0.00	0	0.00	270	0.04
751-1000	0	0.00	0	0.00	0	0.00	0	0.00	212	0.88	0	0.00	0	0.00	212	0.03
1001-1250	0	0.00	35	0.02	624	0.39	561	0.31	1737	7.22	596	5.03	0	0.00	3553	0.49
1251-1500	515	0.40	2729	1.31	4449	2.75	3966	2.22	6191	25.72	2762	23.31	0	0.00	20612	2.87
1501-1750	8672	6.68	24,977	12.01	7255	4.48	5852	3.27	6830	28.38	3690	31.14	42	1.22	57318	7.98
1751-2000	57,934	44.60	111,998	53.84	13,843	8.56	73,995	41.38	4279	17.78	3874	32.69	921	26.83	266844	37.17
2001-2250	62,684	48.25	65,353	31.41	96,823	59.84	86,480	48.37	4387	18.23	929	7.84	2361	68.77	319017	44.44
2251-2500	98	0.08	2942	1.41	38,763	23.96	7947	4.44	164	0.68	0	0.00	109	3.18	50023	6.97
> 2501	0	0.00	0	0.00	45	0.03	0	0.00	0	0.00	0	0.00	0	0.00	45	0.01
total	129903	100.00	208034	100.00	161802	100.00	178801	100.00	24070	100.00	11851	100.00	3433	100.00	717894	100.00

Highlighted parts are where most wild olive trees are found (> 10%)

Table 4: Wild olive crown diameter against elevation

Elevation (meter)	Crown Diameter Size						Total	
	Small		Mid		Big			
	Tree	%	Tree	%	Tree	%	Tree	%
500-750	248	0.06	22	0.01	0	0.00	270	0.04
751-1000	190	0.05	20	0.01	1	0.00	211	0.03
1001-1250	3173	0.81	341	0.15	39	0.04	3553	0.49
1251-1500	17,680	4.50	2571	1.12	361	0.38	20612	2.87
1501-1750	42,920	10.92	10,488	4.55	3460	3.66	56868	7.92
1751-2000	145,393	37.00	86,819	37.66	34,632	36.67	266844	37.17
2001-2250	151,572	38.58	116,983	50.74	50,462	53.44	319017	44.44
2251-2500	31,686	8.06	13,306	5.77	5481	5.80	50473	7.03
>2501	46	0.01	0	0.00	0	0.00	46	0.01
total	392908	100.00	230550	100.00	94436	100.00	717894	100.00

Highlighted parts are where most wild olive trees are found (>10%)

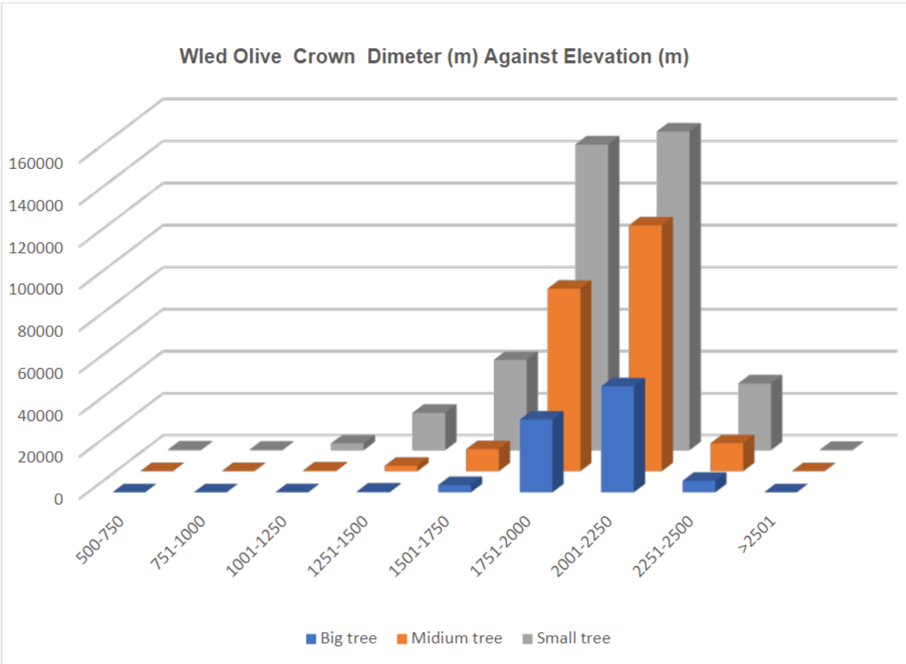

Fig. 8: Histogram showing the pattern of wild olive crown diameter size against elevation

Table 5: The neighboring species of wild olives against elevation

Elevation (meter)	No. of Neighbor Trees						Total	
	Juniper		Acacia		Other			
	Tree	%	Tree	%	Tree	%	Tree	%
500–750	234	0.05	0	0.00	0	0.00	234	0.03
751–1000	178	0.04	0	0.00	0	0.00	178	0.02
1001–1250	3320	0.75	1928	0.44	465	2.08	5713	0.63
1251–1500	17,852	4.01	10,828	2.49	1722	7.69	30402	3.37
1501–1750	44,547	10.00	27,664	6.37	1641	7.33	73852	8.19
1751–2000	165,065	37.05	149,120	34.35	4227	18.87	318412	35.30
2001–2250	178,439	40.05	210,042	48.38	13,805	61.64	402286	44.60
2251–2500	35,821	8.04	34,547	7.96	535	2.39	70903	7.86
> 2501	46	0.01	44	0.01	0	0.00	90	0.01
total	445,502	100.00	434,173	100.00	22,395	100.00	902,070	100.00

Highlighted parts are where most wild olive trees are found (>10%)

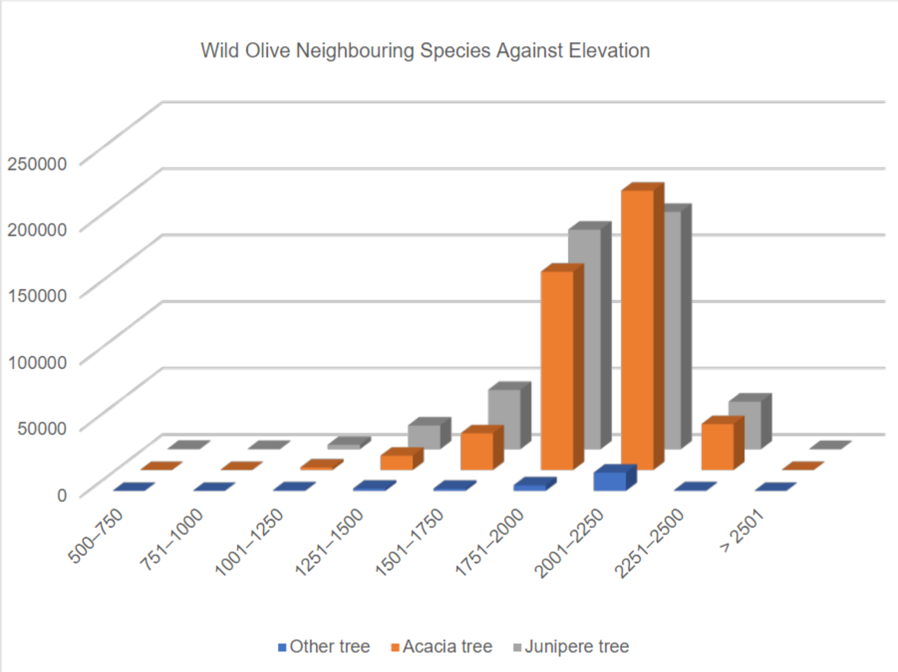

Fig. 9: Histogram showing the pattern of the neighboring species of wild olives against elevation

4. Discussion

Species ranges are shifting, contracting, expanding, and fragmenting in response to global and local environmental changes and human interference with natural topography or landscapes (Chen et al., 2011). Understanding the natural topography where species are abundant indicates the preference or suitability of that species.

This research and development of the wild olive bioinformatics database of the local Al-Baha region have provided new opportunities for analyzing wild olive occurrence data in support of conservation efforts and allowed for a more systematic and evidence-based conservation approach. In this study, the observed species occurrence typically provided information on the areas previously demarcated as having medium to high vegetation density, and the number of trees and location were acquired in a previous study (Al-Ghamdi, 2020b).

In this study, the topography (elevation) preference of wild olive trees was investigated to gain a better understanding of the occurrence and morphology of this species in the study area.

The results show that the majority (81.6%) of wild olives is located at an elevation range of 1,750–2,500m. However, in the Al-Mandaq sub-region, many wild olive trees can also be found at a lower elevation of 1,250–1,500m, while more wild olive presence is found at a higher elevation of 2000–2,500m in the Al-Baha sub-region. This is probably due to the Al-Baha sub-region being the most developed area in the region, where wild olive trees have been cut and consumed in the past to the extent that only those at higher elevations have survived. It was observed that at a lower elevation of 1500–1750m, most wild olive crown sizes are small, indicating that the wild olive prefers a higher elevation to grow well.

Further observations on the species' neighborhood revealed that juniper grows well at lower and higher elevations, while there is more acacia at lower elevations. The abundance of juniper trees in the Al-Mandaq sub-region can be probably attributed to its higher elevation and the rugged nature of its mountains (especially before the introduction of modern roads), which have protected its forests from extensive exploitation as it is not easily accessible. Meanwhile, the small-sized trees and irregular growth show that they have been cut in the past, and the branches growing from them as coppices are considered the current trees.

Alongside these topographical factors, olive trees are known to prefer non-stratified, moderately fine-textured soils, including sandy loam, loam, silt loam, clay loam, and silty clay loam. These provide aeration for root growth, are quite permeable, and have a high water holding capacity. Sandier soils do not have good nutrient or water holding capacity. Heavier clays often do not have adequate aeration for root growth and will not drain well. Olive trees are shallow-rooted and do not require very deep soils (Sibbett and Ferguson, 2004).

Furthermore, according to Sibbett and Ferguson (2004), soils having an unstratified structure of four feet are suitable for olives. Stratified soils, either cemented hardpan or varying soil textures within the described profile, impede water movement and may develop saturated layers that damage olive roots and should be ripped. Olives tolerate soils of varying chemical quality. They produce well on moderately acidic (pH greater than 5) or moderately basic (pH less than 8.5) soils. Basic (alkaline) or sodic soils should be avoided since their poor structure prevents water penetration and drainage, creating saturated soil conditions that kill olive roots.

5. Conclusion

This study successfully identified the preferred topographic (elevation) and landform characteristics favored by wild olives. The findings showed that wild olive trees prefer topography or landform with an elevation between 1,750–2,250m. They have smaller crowns at a lower elevation of 1,500–1,750m and were observed to be associated with both juniper and acacia.

These findings can be regarded as theoretically indicating landforms suitable for olive plantation. As a basis for olive plantation site suitability, these factors are the essential prerequisites. However, further evaluation of social and economic factors is still important. Moreover, it is obvious that site suitability is subject to the temporal dynamics of environmental variables. Therefore, the effects of climate variability and changes in other environmental variables also need to be evaluated so as to plan for future wild olive investment opportunities.

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Compliance with ethical standards

Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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