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MAPPING HUMAN INDUCED LANDSCAPE CHANGES IN ISRAEL BETWEEN THE END OF THE 19TH CENTURY AND THE BEGINNING OF THE 21TH CENTURY

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ABSTRACT

This paper examines changes in Israel's landscape by comparing two time periods, 1881 and 2011. For this purpose we compared land cover derived from the Palestine Exploration Fund historical map to a present land cover map that was compiled from 38 different present-day GIS layers. The research aims were (1) to quantitatively examine what were the changes in Israel's landscape between 1881 and 2011; (2) to identify and explain spatial patterns in these landscape changes. Landscape transformation was categorized into five classes: 'residual bare' (no change in natural vegetation, mostly in desert areas); 'residual' (i.e. remnant; no change in natural vegetation class); 'transformed' (changes between different natural vegetation areas); 'replaced' (area which became managed); 'removed' (no or minimal natural vegetation). We found that only 21% of the area retained similar landscape classes as in the past, with the largest changes taking place in ecoregions that were favorable for developing agriculture – Jezre'el Valley and the Sharon Plain. Two physical factors had a strong effect on the type of change in the landscape: (1) most of the agricultural areas and human settlements were found in areas ranging between 400-600 mm/year (2) natural land cover features were more common in areas with steeper slopes. We found that the majority of protected areas, 54.6%, are comprised of remnant vegetation classes (i.e. residual transformation class) however more than half of protected areas are located in desert areas and are thus biased in their representation of land cover classes.

Keywords: GIS; historical maps; land cover/use; compilation; landscape transformation/changes.

INTRODUCTION

Landscapes are important due to their historical, cultural, environmental and economic values (Meinig, 1979). Geographers, archeologists, historians, ecologists, planners and other scholars examine landscapes to learn about natural and human history (Andersen, Crow, Lietz, & Stearns, 1996; Antrop, 2005; Lindborg & Eriksson, 2004; Skanes & Bunce, 1997). Moreover, landscape reconstructions are crucial for the present since they allow us to estimate changes and transformations (or in other words vegetation change) in habitat areas and their diverse causes (Antrop, 2005; Ellis, Siebert, Lightman, & Ramankutty, 2010; Foster et al., 2003). Several papers have reconstructed past landscapes for the purpose of comparing them to different time periods as well as to present day, either at the local scale (Fensham, 2007; Grossinger, Striplen, Askevold, Brewster, & Beller, 2007; Levin, Elron, & Gasith, 2009; Petit & Lambin, 2002; Sanderson & Brown, 2007; Thackway & Lesslie, 2008) or at global scales spanning several centuries (Ellis, et al., 2010) or millennia (Ellis, 2011). Parallel to the worldwide increase in land cover transformation, mainly due to human needs and population growth, the rise in environmental awareness has led to the formation of protected areas, a new form of land use, in the late 19th century (Chape, Harrison, Spalding, & Lysenko, 2005).

The sources for reconstructing past landscapes are varied and it is often the case that historical maps, aerial photos (from World War I onwards) and satellite images (from the 1960s onwards) are used separately or in combination to reconstruct the past (Knowles & Hillier, 2008). While historical maps allow examination of longer periods of time than aerial photos or satellite imagery, their use requires us to correctly interpret the symbology used, estimate inaccuracies in the map and other uncertainties in the extraction of data obtained from these sources (Leyk, Boesch, & Weibel, 2005). Once past and present data have been obtained, not only can we learn about the total changes, we can also examine transformation (e.g., vegetation changes) processes (Pan, Domon, De Blois, & Bouchard, 1999; Thackway & Lesslle, 2006). Transformation of the landscape can be due to either human intervention or physical factors (i.e. climate, soil), but in most cases it is a combination of both.

Israel is a distinctive geographical and historical area. Geographically, Israel is located in between three continents (Asia, Africa and Europe) and has a large range of climates, soils and topography which together creates a varied landscape and diverse habitat (Danin, 1988; Medail & Quezel, 1999). The uniqueness of this region is that the Middle East (including Israel) was one of the first places in the world where domestication of plants began, leading to the agricultural revolution around 10,000 years ago. This revolution also led to the beginning of human settlement (Paz, 1980; Reifenberg, 1950; Thirgood, 1981). Population size and the extent of intensive human land use in Israel/Palestine have gone through several periods throughout its history. While during several periods there was an increase in population size (e.g., during the later Roman/Byzantine era, when between one to several million people were estimated to live in Western Palestine (Bar, 2004)), during other periods there was a decrease in population size (such as the Ottoman period, with less than 400,000 people in Western Palestine in the beginning of the 19th century (Kark & Levin, 2012)). These changes have been attributed to both climatic and human factors (Issar & Zohar, 2009; Reifenberg, 1950).

The beginning of the modern era in Israel started in the 19th century with the gradual decline of the Ottoman Empire and a gradual rise of foreign influence which brought economic development and rapid population growth mainly due to immigration (Ben-Arieh, Bartal, 1983; Kark, Denecke, & Goren, 2004; Naveh, 1981). By 1948 Israel's population has reached nearly two million, and by 2013 the population of the State of Israel including the West Bank and Gaza Strip stood at 12 million (Bachi, 1977; C.I.A, 2013). Population growth has dramatically transformed the landscape with obvious changes in land cover type and extent.

Given the dramatic increase in population size, the aims of this research were:

1. To quantitatively examine the changes in the landscape of Israel by comparing changes between land cover maps for two time periods, the late 19th century and the present.

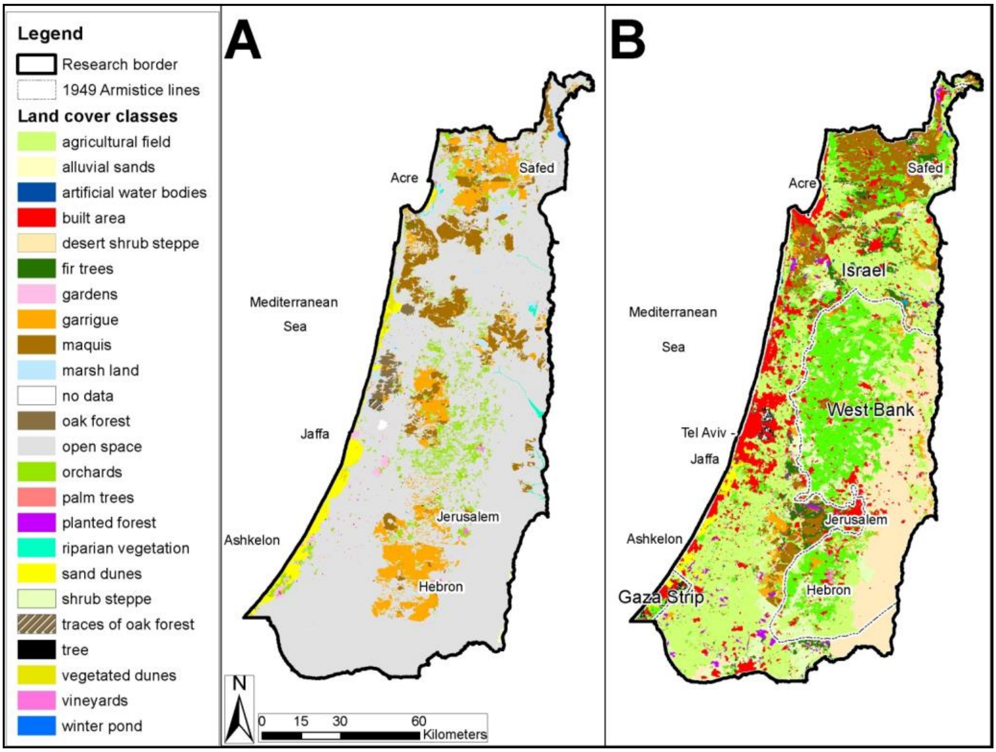
2. To identify spatial patterns in these landscape changes and try to explain some of these changes.

METHODOLOGY

Study area

The study area covers about 14,700 square kilometers, representing 94.3% of the total area covered by the Survey of Western Palestine maps of the Palestine Exploration Fund (PEF) (Conder & Kitchener, 1871-1877) (Figure 1A). The study area roughly covers the central and northern part of the present-day State of Israel (between 34°10'-35°45' E, and 31°13'-33°18' N).

Fig. 1: Digitized land cover map of the study area in the 19th century (1881) as was depicted on the PEF map (A). Digitized land cover map of present day study area (2011) complied from 38 different GIS layers (B).



Study sources

Sources for reconstructing past land cover

The main historical source used in this research was the digitized PEF map which is a very valuable source for understanding the past landscape of Palestine (Conder & Kitchener, 1871-1877). This map was prepared by surveyors from the British Corps of Royal Engineers between 1871-1877 (published in 1881) providing a rare and unique glimpse into the land cover at the beginning of the modern era of Palestine (Conder & Kitchener, 1871-1877; Conder, Kitchener, Palmer, Besant, 1881). The PEF map features the land cover in great detail (scale of 1:63,360) and includes 18 land cover classes such as built-up areas and different natural features, and is considered to be the first accurate topographic map of Israel (Levin, 2006). Several studies have used the PEF survey map as a source to depict 19th century land cover of Palestine (Levin, 2006; Levin et al., 2009; Margalit, 1955; Schick, 1955). The map was geo-referenced by Levin (2006) using 123 control points of trigonometrical stations and 1st order polynomial, with a root mean squared error of 74.4 m.

Sources for mapping the present land cover

As there was no nationwide land cover mapping available for Israel detailing natural vegetation classes, we created such a map by combining 38 different GIS layers (Table S1) which partially overlapped each other. The GIS layers used were different from each other, in their scale, year, aims, mapping method (e.g., field work, aerial photos, satellite imagery), areal extent, the vegetation classes used and the organization in charge of the mapping. Since most of our GIS layers were at a scale of 1:10,000-1:20,000, the compilation of all the GIS layers at a spatial resolution of 50 meters was relatively detailed and was reasonably equivalent in scale and information content to the PEF map. As in many cases several overlapping maps assigned different land cover classes to the same area, we had to consider which land cover class to use.

Land cover classification and compilation of the layers into one single layer was done in two steps. The first step was to arrange the 38 layers in order of priority, according to the scale, year (ranging between 1993 and 2011) and the vegetation classification used in each of the source layers (Table S1). The second step was to compile the 38 different GIS layers, based on their level of priority (shown in Table S1). The compilation resulted in a single layer depicting present-day land cover (Figure 1B). Here we used the same land cover classes appearing on the PEF map in addition to six additional classes such as artificial water bodies and agricultural fields that were not shown on the PEF maps. To present the correspondence and coverage of the 38 GIS layers used for generating the present day land cover map, we calculated two statistics: (1) The number of times each grid cell was included in one of the present-day input maps; (2) The coherence of land cover classes in each pixel (Figure 2). The calculation of coherence was done using the 'variety' option with the 'Zonal Statistics' tool in - ArcGIS 10.1 (ESRI, 2014). The maximum variety found in a single pixel was seven different land cover classes (i.e. weak coherence) and the minimum variety found was one single land cover class (i.e. strong coherence). Lastly, we also measured the fragmentation (number of patches) of the land cover of the digitized PEF map and of the present-day map using IDRISI Selva (Clark Labs, 2012).

Examining overall changes between the land cover of the past and the present

Here, we calculated the area size of the different land cover classes, using the original 24 classes as well as six additional generalized ones (Table 1).

We calculated a transformation matrix for each of the 24 land cover classes, to examine landscape transformation between the past PEF map and the present.

Fig. 2: Map representing the number of times an area was mapped in different GIS layers used to compile a map of present day (A). Map representing the level of coherence of the land cover classes between the different GIS layers used (B)

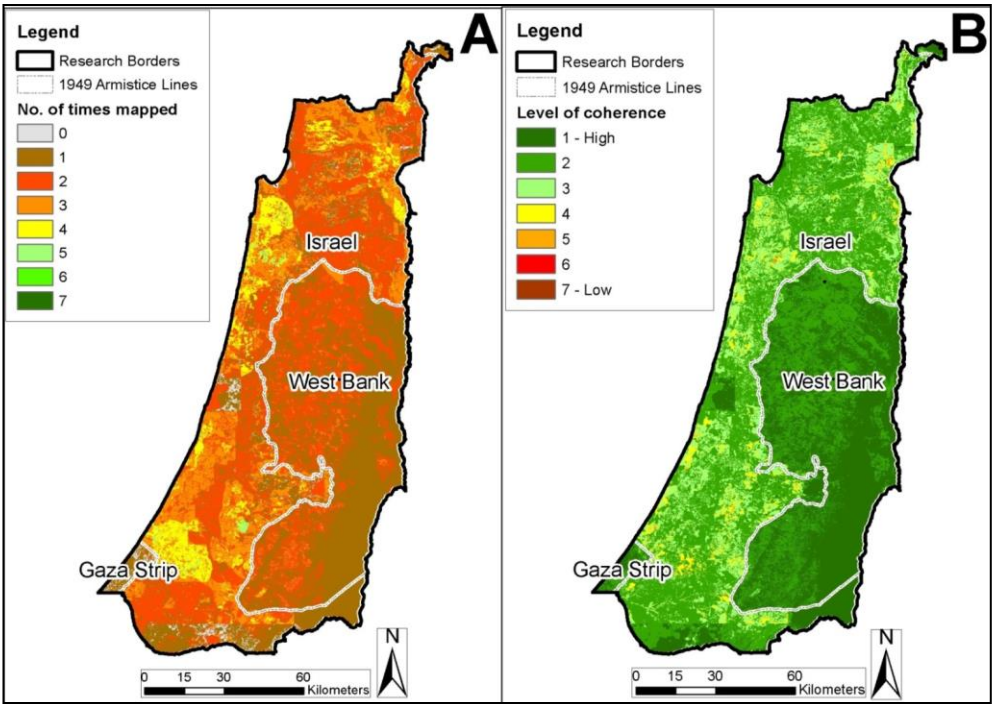


Table 1: Land cover classes used in this study. Generalized land cover classes were used to calculate landscape transformation classes (shown on Table 2)

Land cover categories	Generalized land cover categories	Explanation on generalized classes
Alluvial sands	Bare area	Area with non or minimal vegetation land cover as a natural state such as desert areas or due to natural succession process such as primary shrub area
Desert shrub steppe	Bare area	
Sand dunes - PEF map	Bare area	
Agricultural field	Managed area	Area of managed land cover such as agriculture and plantation
Fir trees - Present map	Managed area	
Gardens	Managed area	
Orchards	Managed area	
Palm trees	Managed area	
Planted forest	Managed area	
Vineyards	Managed area	

Shrub steppe	Natural vegetation area	Area with highly natural vegetation land cover such as woodland
Maquis	Natural vegetation area	
Marsh land	Natural vegetation area	
Riparian vegetation	Natural vegetation area	
Sand dunes - Present map	Natural vegetation area	
Garrigue	Natural vegetation area	
Oak forest	Natural vegetation area	
Traces of oak forest	Natural vegetation area	
Tree	Natural vegetation area	
Vegetated dunes	Natural vegetation area	
Winter pond	Natural vegetation area	
Fir trees - PEF map	Natural vegetation area	
No data	No data	No available data on specific area
Open space	Open space	Bare area (in desert areas), batha area (in Mediterranean areas)
Artificial water bodies	Removed area	Area with no vegetation land cover such as built up areas
Built area	Removed area	

Examining spatial patterns of the change found between the past and the present

To facilitate the understanding of the major landscape transformations, we adapted the Vegetation Assets, States and Transformations (VAST) classification framework (Thackway & Lesslie, 2008; Thackway & Lesslle, 2006), to examine five major transformation land cover classes which represent the changes in the land cover from the past to the present (Table 2). The land cover transformation classes were: 'residual bare' (i.e. remnant: no change in class of natural vegetation, mostly desert areas); 'residual' (i.e. remnant: no change in class of natural vegetation); 'transformed' (changes between different natural vegetation classes); 'replaced' (areas which became managed either for agriculture or as planted forests); 'removed' ('urbanized' area, area with no or minimal natural vegetation). This framework measures the change in the vegetation against a putative base-line which in our case is the past land cover depicted on the PEF map.

Lastly, we examined the spatial distribution of Israel's protected areas (nature reserves and national parks, in all statutory classes), with respect to landscape transformations. For this purpose we used the GIS layer from the Israel Nature and Parks Authority of present day nature reserves and national parks (INPA, 2010).

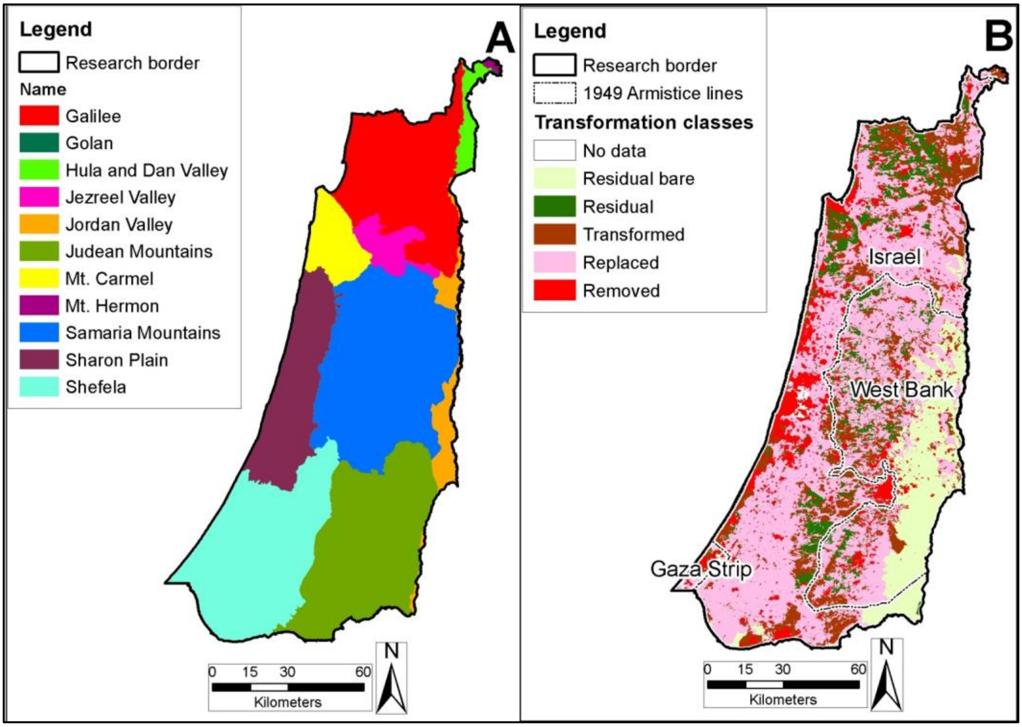
Table 2: The five transformation classes from the past to the present landscape

Transformation type	Explanation	Examples
No data	No data available on land cover	
Residual bare	No change in natural bare areas	open space (in desert areas) → bare areas
Residual	No change in natural vegetation areas	natural vegetation areas →natural vegetation areas
Transformed	Transformation is between different natural vegetation areas as well as areas that were managed or removed and have returned to be areas of natural vegetation areas.	open space (not in desert areas) → natural vegetation areas Or managed areas → natural vegetation areas / bare areas Or natural vegetation areas → bare areas Or bare areas → natural vegetation areas Or removed areas → natural vegetation areas / bare areas Or natural vegetation areas → another class of natural vegetation area
Replaced	Replaced is an area which became a managed area such an area of agricultural land or planted forest.	open space → managed areas Or natural vegetation areas / bare areas → managed areas Or removed areas → managed areas
Removed	Removed is an area which has become an area with no or minimal/artificial vegetation due to intense human activity such as built up areas	natural vegetation areas / bare areas / managed areas / open space / removed area → removed areas

Explaining land transformations

We calculated the amount and type of transformation within 11 geographic ecoregions, using the geographical classification of Rotem - Israel Plant Information Center (2003) (Figure 3A). We examined the type and amount of landscape transformation as a function of slope and rainfall (as in areas below 900 mm/year, water constitutes a binding constraint to higher densities of human population; (Le Blanc & Perez, 2008)). To this end, we used a Digital Elevation Model (DEM) at a spatial resolution of 25m to create six slope classes ranging from 0 – 74 percent (Figure S1), and a digitized map of the mean annual rainfall of Israel (digitized by Kadmon and Danin (1999) from a 1:250,000 rainfall map) ranging between 0 - 1000 mm/year, which was divided into five rainfall classes (Figure S2).

Fig. 3: Map representing the 11 ecoregions found in the study area (A). Map representing the five transformation classes between the two time periods examined (1881 and 2011) and upon it the borders of the ecoregions.



RESULTS

Coherence of the GIS layers used to map the present land cover

The majority (74%) of the study area had just one or two input GIS layers representing the present, available for each grid cell (Table 3, Figure 2A), and 79% of the study area was identified as highly coherent (level 1 and 2) with respect to the land cover classes (Table 4 and Figure 2B).

Table 3: The number of times an area was mapped in the different GIS layers used to compile the present day vegetation map

Number of times an area was mapped	Total in km²	Percent of total study area (%)
0	261.7	1.8
1	5206.3	35.4
2	5756.1	39.1
3	2520.4	17.1
4	885.3	6
5	83	0.6
6	3	0.02

Table 4: The level of coherence of land cover classes between the different GIS layers used to compile

Level of coherence of landscape classes	Total in km²	Percent of total study area (%)
1 - high	4401.2	29.9
2	7260.9	49.3
3	2513.9	17.1
4	497.6	3.4
5	40.7	0.3
6	1.6	0.01
7 - low	0.02	0

Overall changes between the land cover of the past and the present

Land cover in Israel underwent great changes between the late 19th century (Figure 1A) and the present (Figure 1B). The most dominant land cover classes in the 1870s were 'open space' (77.8%) followed by 'garrigue' (6.5%) and 'maquis' (6.2%) (Table 5). On the other hand, the most dominant land cover classes at the present were 'agricultural fields' (30%) followed by 'orchards' (17.4%), 'desert shrub steppe' (12.2%) and 'built-up areas' (12%) (Table 5). Some land cover classes shown on the PEF 1870s map did not exist in the present land cover map, such as 'open spaces' (referring to land cover which was not defined on the PEF map) and 'traces of forest' (relating to coastal forests cut down in the 19th century). Conversely, some present-day human-related land cover classes did not exist in the past, such as 'artificial water bodies' and 'planted forest'.

Relative to the past land cover classes, the largest decrease in area was in 'marsh land' (-93.4%), 'winter pond' (-70.4%), 'gardens' (-66.9%), 'garrigue (-59.2%) and 'riparian vegetation (-58%) and the classes showing the largest increase from their past area were 'fir trees' (+11710.7%), 'built-up area' (+7165.7%), 'orchards' (+329.7%) and 'vineyards' (+294.1%) (Table 5).

Table 5: Changes in overall area of the 24 land cover classes in the study area, comparing the PEF map and the present

*N/A in the table means that this class does not exist due to: 1. Not subject focus of the map; 2. Generalization of classes. **Oak forest – the present distribution of oak trees and forests were generalized and are found under 'maquis' class. *** Planted forest - many of which are 'fir trees'.

Land cover classes	PEF map (1881)			Present map (2011)		PEF area change in land cover classes relative to the past	
	Percent of total study area (%)	Percent of total study area not including 'open space' class (%)	Area in km²	Percent of total study area (%)	Area in km²	Percent differences in (%)	Sum differences in km²
Agricultural field	N/A	N/A	N/A	30	4409.7	N/A	N/A
Alluvial sands	0.18	0.79	25.9	N/A	N/A	N/A	N/A
Artificial water bodies	N/A	N/A	N/A	0.54	79.1	N/A	N/A
Built area	0.16	0.74	24.2	12	1758.3	+7165.7	+1734.1
Desert shrub steppe	N/A	N/A	N/A	12.2	1793.6	N/A	N/A
Fir trees	0.02	0.08	2.8	2.2	330.7	+11710.7	+327.9
Gardens	0.45	2	66.2	0.15	21.9	-66.9	-44.3
Garrigue	6.5	29.4	960.7	2.7	391.2	-59.2	-569.6
Maquis	6.2	27.8	909.8	7.5	1106.7	+21.6	+196.9
Marsh land	0.57	2.6	83.6	0.04	5.5	-93.4	-78.0
No data	N/A	N/A	N/A	1	209.9	N/A	N/A
Oak forest	0.74	3.3	109.1	N/A	N/A	N/A	N/A
Open space	77.8	0.0	11446.9	N/A	N/A	N/A	N/A
Orchards	4.1	18.3	596.9	17.4	2564.9	+329.7	+1968.0
Palm trees	0.03	0.12	3.9	N/A	N/A	N/A	N/A
Planted forest	N/A	N/A	N/A	1.8	264.4	N/A	N/A
Riparian vegetation	0.43	1.9	63.6	0.18	26.7	-58	-36.9
Sand dunes	2.1	9.6	314	2	234.1	-25.4	-79.9
Shrub steppe	N/A	N/A	N/A	9.4	1386	N/A	N/A
Traces of oak forest	0.19	0.83	27.2	N/A	N/A	N/A	N/A
Tree	0.01	0.06	1.9	N/A	N/A	N/A	N/A
Vegetated dunes	0.29	1.3	42.5	0.2	28.9	-32	-13.6
Vineyards	0.16	0.73	23.8	0.64	93.8	+294.1	+70.0
Winter pond	0.10	0.43	14.2	0.03	4.2	-70.4	-10.0

Comparing 'open space', which represents 77.8% on the PEF map, corresponding present day classes would cover only 51.6% of the total study area if we included the following classes: 'desert shrub steppe', 'shrub steppe' and 'agricultural fields' (which may be irrigated in the present, in contrast with the past). Otherwise, without including 'agricultural fields' it would represent only 21.6% (Table 5).

In addition to changes in area of land cover classes, the landscape became more fragmented, the total number of patches increased from 8,405 on the PEF map, to 104,602 in the present. The classes with the largest number of patches in the past were: 'orchards' (3846), 'maquis' (1205), 'garrigue' (999) and 'built-up areas' (752) and the classes with largest numbers of patches in the present were: 'orchards' (25070), 'agricultural fields' (23614), 'built areas' (14077) and 'shrub steppe' (13740). Some land cover classes experienced both a decrease in their area and increased fragmentation; e.g., the total area of sand dunes decreased from 314 km2 to 234 km2, whereas the number of sand dunes patches increased from 28 to 469 (Table S2). Another example of this trend can be also found with regard to 'garrigue' where on the PEF it represented 6.5% of the total area and included 999 patches and on the present-day map it represented only 2.7% of the total area with 3807 patches.

Overall, 'natural vegetation' areas experienced a slight increase from 15% on the PEF map to 22% at present (Table 6). With regards to 'managed areas' and 'removed areas' there was a dramatic increase in their area between the PEF map and the present. 'Managed areas' increased from 4.7% in the PEF to 52.2% in the present and 'removed areas' increased from 0.16% in the PEF to 12.5% in the present (Table 6). Indeed, 64.1% of the 'open space' areas on the PEF were transformed into human land uses such as 'agricultural fields', 'orchards' and 'built-up areas' (Tables S3, S4, S5).

Table 6: Data extracted from the digitized PEF map and from the compile present day map of the six generalized land cover classes in the study area

Generalized land cover classes	PEF map (1881)			Present map (2011)	
	Percent of total study area (%)	Percent of total study area not including 'open space' class (%)	Area in km²	Percent of the total area (%)	Area in km²
No data	N/A	N/A	N/A	1.4	209.9
Bare area	N/A	N/A	N/A	12.2	1793.6
Open space	80.1	N/A	11786.7	N/A	N/A
Natural vegetation area	15	75.5	2212.6	22	3183.7
Managed	4.7	23.7	693.6	52.2	7685.4
Removed	0.16	0.82	24.2	12.5	1837.4

Spatial patterns of change between past and present day land cover

The majority of the study area, 77,7%, was altered and only 21% of the study area remained under the same landscape class it was in the PEF (Table 7, Figure 3B). The biggest transformation classes was 'replaced', 49.8% of the total study area becoming managed, used for agriculture or replaced by planted forests. The smallest transformation class was 'residual' covering only 9.1% of the total study area (Table 7). The transformation class 'residual bare' was dominant along the arid Jordan Rift Valley (Figure 3B).

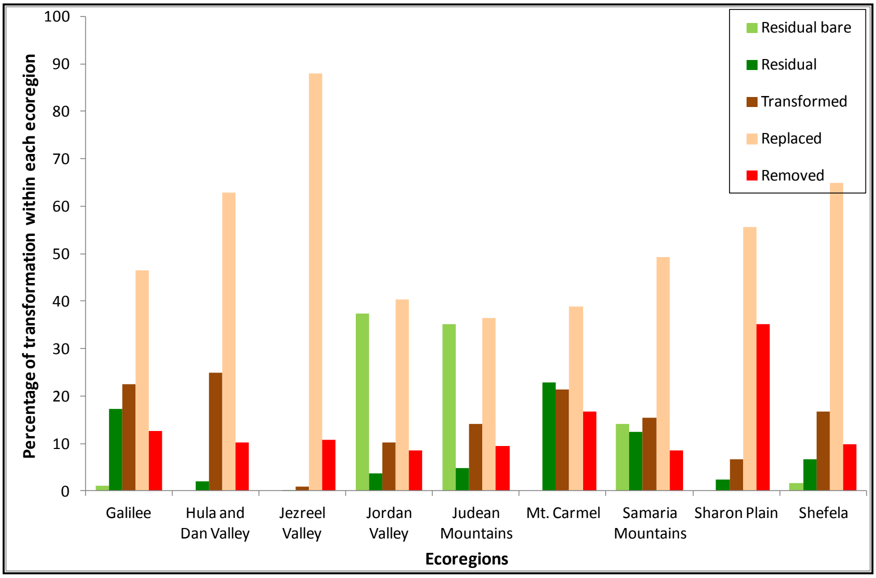
In all the ecoregions the most dominant transformation class was 'replaced' (areas which became managed either for agriculture or as planted forests) (Figure 4). The ecoregions that experienced the greatest transformation to intensive human use (replaced and removed) were located in the main valleys (Jezre'el, Hula and Dan valleys) and along the coastal plain (Shfela, Sharon) (Figure 3, 4).

Table 7: Spatial distribution of landscape transformation classes with respect to protected and non-protected areas

Transformation classes	Total area		Protected areas	
	Percent of total study area (%)	Area in km²	Percent of protected areas (%)	Area in km²
Residual	9.1	1321	20	253.9
Residual bare	11.9	1738	34.6	439.8
Transformed	15.4	2242.6	24.8	315.1
Replaced	49.8	7259.9	18.3	232.9
Removed	12.5	1827.7	1.6	20
No data	1.2	179.5	0.71	9

Fig. 4: The amount and type of transformation of the land cover between the two time periods (1881 to 2011) divided into the nine ecoregions

In this figure we omitted two ecoregions, Mt. Hermon and the Golan, since they are not represented enough in the PEF map (0.23% of the total study area).



Concerning protected areas, only 8.6% of the study area (1271 sq km out of 14700 sq km) was found within them (Table 7). One quarter of the protected areas, 34.6%, were located in 'residual bare' areas (i.e. arid areas), followed by 24.8% of these protected areas located in 'transformed' areas (Table 7).

Physical factors explaining land cover transformation

Land cover transformations corresponded with slope and rainfall. Gentle slopes were associated with a greater transformation to human land uses (replaced and removed), while the transformation classes of residual and residual bare (i.e. the least transformed areas) were more common in areas of steeper slopes (Figure 5).

Fig. 5: The percentage of each transformation class within slope classes (in percentage)

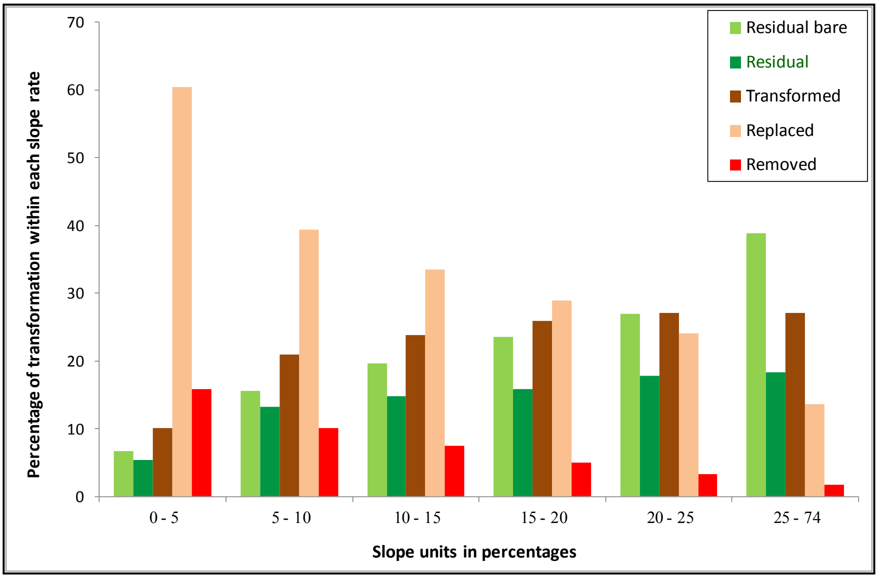
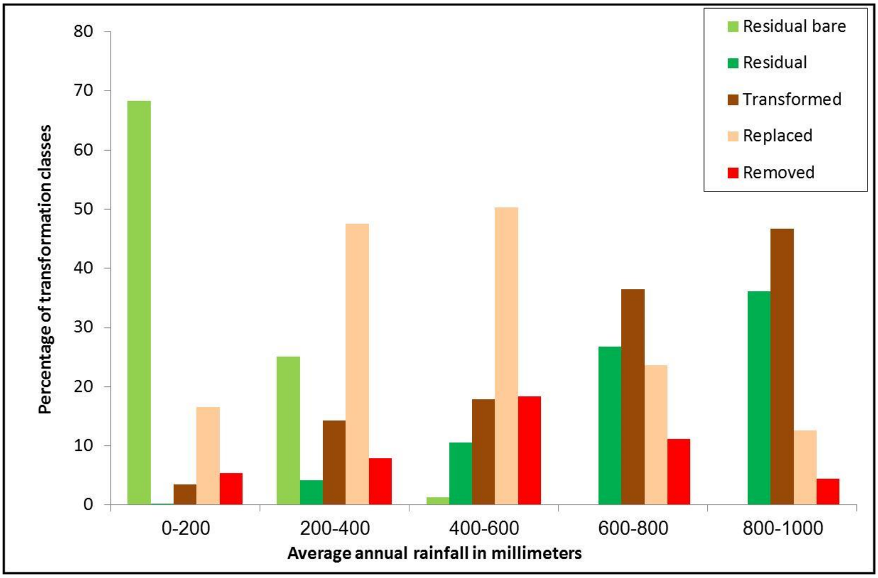


Fig. 6: The percentage of each transformation class within rainfall classes (mm/year)



Land transformation exhibited a unimodel response to rainfall, with a greater transformation to human land uses (replaced and removed) peaking between 400-600 mm/year. The residual transformation classes were dominant in areas with either low rainfall (below 200 mm/year; residual bare) or high rainfall (above 600 mm/year; residual and transformed) (Figure 6).

DISCUSSION

Quantitative changes in the landscape of Israel between two time periods: 1881 and 2011

The first aim of this research was to quantitatively examine the changes in landscape of Israel by comparing changes between land cover classes of two time periods, 1881 (past PEF map) and 2011 (present day map). The past land cover map reconstructed from the PEF map had a total of 17 landscape classes whereas on the present-day map compiled from 38 GIS layers there was a total of 19 classes (Figure 1, Table 5). The past landscape was much less fragmented than the present one (Table S2, Figure 1A, 1B). Furthermore, the majority of the land cover classes had an increase in the number of patches accompanied by a decrease in their area ('garrigue', 'marsh land') or an increase in their total area ('maquis', 'orchards') (Table S2). Fragmentation may form obstacles for some species to move between their habitat patches (Levin et al., 2009), and is considered to be one of the two prominent factors leading to species extinction (Fahrig, 1997). The more the landscape is fragmented, it is less likely to be ecological functioning, and to be preserved in its original form (Keitt, Urban, & Milne, 1997).

In the past Palestine's main land cover class was 'open space'. The literature reveals that 'open space' includes different features in different areas such as the batha landscape in the Mediterranean areas, non-irrigated agricultural fields and grazing lands (Conder, Kitchener, Palmer, & Besant, 1881; Tristram, 1884). Such areas were often classified in the past as 'mawat' ('dead land') which roughly correspond with areas beyond 2.4 km around villages as well as bare landscape areas in the desert (Conder, Kitchener, Palmer, & Besant, 1881; Conder, Kitchener, Palmer, Besant, & Palestine Exploration Fund, 1881; Shehadeh, 1982; Tristram, 1884). By the end of the 20th century, most of the 'open space' class have been transformed into intensely managed agricultural areas making use of Israel's advanced national water carrier system (Figure 1, Figure 5) (Feitelson, 2013; Feitelson, Selzer, & Almog, 2014). Other areas that were classified in the past as 'open space', have either been transformed into 'built-up areas', or are used for grazing in arid areas (Figure 1, Figure 5). The results show that there was a decrease of 33.6% or as much as 72.2% (depending if agricultural fields are considered or not) in present day classes which could have represented what was in the past PEF areas of 'open space'. In the last 130 years there has been an increase in forested landscape which includes 'maquis' and 'planted forest' (at present 9.3 % of the total study area). Since forested areas have increased with time, their conservation priority should be lower than for landscape classes which decreased in area and became more fragmented (e.g., wetlands). One of these classes should be the present day 'shrub steppe' which was one of the classes included in the past 'open space'. The research revealed that 54.6% of the protected areas in Israel are comprised of 'residual' areas. However, a large part of protected areas, 34.6%, were comprised of 'residual bare' areas, meaning desert areas (Table 7) (Joppa & Pfaff, 2009). Indeed, one of the largest protected areas with respect to the size of the geographical landscape unit is located in the Judea Desert. In contrast, the regions with the smallest protected areas are the Sharon Plain and the Shfela, both being densely populated areas. The location of protected areas in Israel is biased towards infertile, steep and desert areas, as was also found for the USA (Joppa & Pfaff, 2009). In our view, one of Israel's conservation priorities should be to protect the 'shrub steppe' (or in other words the Mediterranean batha vegetation) class of vegetation and its unique landscape and biodiversity. Not only,that there has been a decrease in their area (part of the past 'open space') (Table 5) but areas with 'shrub steppe' have become more fragmented (Table S2). Indeed, large part of 'shrub steppe' (batha) plants are listed in the list of endangered species (Shmida & Polak, 2007).

In the present-day map there are new human-created landscape classes which did not exist in the past such as 'artificial water bodies' and 'planted forests' (Table 5). Some transformations were related to changes in the traditional practices of cutting down trees and grazing, which were widespread for centuries in the region. Due to past practices of heavy grazing, which inhibited the development of maquis, such practices were not allowed within the State of Israel for several decades, nonetheless in the West Bank this practice continues to this day (Levin & Ben-Dor, 2004; Levin & Heimowitz, 2012). This enabled the recovery of large tracts of garrigue and maquis in Israel's Mediterranean landscapes (Carmel & Kadmon, 1999; Perevolotsky & Seligman, 1998). Since the 1990s, the important role of managed grazing has been recognized (for various reasons, such as reducing fire risks, opening the landscape, increasing biodiversity) and it is now being used as a management tool in Israel (Levin et al., 2013; Perevolotsky & Seligman, 1998). Another major transformation in Israel's forest landscapes concerns fir trees. The highest increase (in percentages) of land cover between the PEF map and the Present map was in fir trees. While in the 19th century there were some natural stands of fir trees (*Pinus halepensis*, some of which were also shown on the PEF map) (Liphschitz & Biger, 2001), at present 75% of planted forests are a wide variety of coniferous trees (Liphschitz & Biger, 2001; Perevolotsky & Sheffer, 2009). The reasons for preferring to plant coniferous trees in the past (and mostly pine trees until the 1970s) were that these trees were found to grow quickly, were well adapted to dry habitats, and it was thought that not only can they provide recreational and shading areas but also wood for production (Perevolotsky & Sheffer, 2009).

The results of the comparison made between the past and present showed that the landscape classes which have increased the most in their area were human modified ones: 'orchards' and 'built-up areas' as well as plantation of 'fir trees' (Table 5). Indeed, the modernization process which started in the 1830s and onwards was followed by a growth in population and agricultural areas (Ben- Arieh, 1981; Frantzman, 2010; Gerber, 1982; Kark, et al., 2004; Shamir, 1985). If in 1875 the estimated population in Palestine was around 450,000, the population of Israel including Gaza Strip and the West Bank in 2013 had reached 12 million (Bachi, 1977; C.I.A, 2013). As a consequence, at present there are several large urban areas, especially along the coastal plain (Figure 1B). The new villages founded between 1877 and 1922 (69 Arab villages and 58 Jewish villages) were based on farming and agriculture (Frantzman, 2010; Kark, 1983). In the same period, the Zionist ideology of the new Jewish immigrants at that time was to make the land fertile and green by promoting agriculture (Kark, 1983; Penslar, 1991). In addition, the importance of agricultural development was further promoted with the creation of the State of Israel in 1948 and went on until the late 1950s, when the government started placing less importance on the agricultural sector, and preferred the development of other sectors such as industry, commerce and services (Kellerman, 1993).

The landscape classes with the largest decrease in area relative to the past land cover were: 'marsh land', winter ponds', 'gardens' and 'garrigue' followed by 'riparian vegetation', 'vegetated dunes' and sand dunes' (Table 5). Most of the 'sand dune', 'vegetated dunes' 'marsh land' and 'winter pond' areas during the 19th century were found along the coastal plain (Figure 1A). Once the process of development started, 'sand dunes', 'vegetated dunes' and 'marsh lands' were seen as waste lands to be altered and 'winter ponds' were exploited for agriculture or for human settlement (Ahiron-Frumkin et al., 2003; Sewell & Macgregor, 1920). Today the coastal plain is dominated by large urban areas and remnants of agricultural areas between them (Tel-Aviv being Israel's largest metropolitan area).

There was a decrease in the area of 'garrigue' by more than half (from 6.5% in the PEF map to 2.7% at present) (Table 5). 'Garrigue' is an area dominated by bushes of 0.50 to 1.50 meters and it is one of the stages in the succession of Mediterranean forest. Possible explanations for this decrease is (1) that 36% of the areas have been taken over for agriculture both as 'agricultural fields' and 'orchards' (Table S3), and (2), that remnant natural areas which have been protected and managed have received better conditions for development and consequently the vegetation there evolved over the years to a higher succession level (i.e. from 'garrigue' to a more dense vegetation area such as 'maquis') (Carmel & Kadmon, 1999).

The decrease in the area of 'riparian vegetation' can be attributed to three reasons. The first is that agricultural areas took over as in the case of 'garrigue' (Table S3). The second is that many of these rivers and river banks have been transformed into discharge water ways in urban areas such as the Ayalon River in Tel Aviv and the Gaaton River in Naharia, while others have become recreational areas such as the Yarkon River in Tel Aviv, but often without the restoration of the natural vegetation landscapes (Gabbay, 2001; Katz & Tal, 2013). Lastly, other areas of 'riparian vegetation' in the past which have disappeared or decreased are a result of years of drought and mismanagement of water supplies which dried up rivers and the vegetation on their banks (Katz & Tal, 2013). However, this situation has started to change due to the recognition of nature's right for water in the Water Law of 2005 (Laster & Livney, 2009) and as Israel is using more desalinized water for domestic, agriculture and industry leaving more water for nature (Feitelson & Rosenthal, 2012).

Spatial patterns and reasons for transformations in the land cover

Landscape changes may be the result of anthropogenic and of climatic changes. However, in the 20th century it can be assumed that most of the nature and landscape changes are primarily a result of human actions (Messerli, Grosjean, Hofer, Nunes, & Pfister, 2000), as was also found in our study, where most landscape transformations were to human modified classes. Indeed, Israel's transformation of the land was very much related to different ideological and geo-political trends during these years. For example, the broad spatial distribution of built-up areas in the study area was partly a result of continued conflict over the land (between Arab and Jewish settlers) in the first two decades since the creation of the State of Israel and the Israeli policy to spread the population as much as possible in order to control as much land as possible (Shoshany & Goldshleger, 2002) .

In Israel, maquis, forests and river banks are managed in some way or another. One reason for the management of these natural areas is that since Israel is one of the most densely populated countries in the world, every territory that is not built-up is carefully divided into designated areas for future building, agricultural, natural areas and so on, in national, regional and local master plans (Alfasi, 2006; Shoshany & Goldshleger, 2002). A second reason for the management of maquis and forest areas is to avoid fires which are very common in this semi-arid climate and are mostly attributed to human causes (Levin & Heimowitz, 2012). Some of the tools used for fire management are allowing grazing in areas of shrubs and planning and planting less flammable trees (Levin, et al., 2013; Neeman, Lahav, & Izhaki, 1995). A third reason for the management of natural areas is that many of the planted forests are located in harsh areas and for its initial success of tree rooting a strong intervention was needed. From the middle of the 19th century much of the afforestation that took place was by using species which not always best suited the soil and climate of the region, as well as by using non-native species (e.g. eucalypt species) and thereby require special management until today (Amir & Rechtman, 2006). Lastly, many of the protected areas in Israel are managed, due to the need to address negative trends and threats found in the different fragmented ecosystems (Safriel, 2010). For instance, to prevent fires of protected areas, clearing of areas around protected areas by cutting down trees and burning shrub areas are often used (Ne'eman, 1995).With regards to the rest of the study area, 21% of 'residual' and 'residual bare' areas are areas retaining the same landscape class as in the past (although its state might have changed) (Table 7). However, also in these areas, change has occurred such as in the 'residual' areas where batha and garrigue areas have advanced in the succession cycle and have mostly become maquis as was found in the results (Table 5). Some of the landscape transformations were explained by physical factors. For example, areas less attractive to human settlement and agriculture such as areas with sharp gradients (above 5%) and under 200 mm/year of rainfall corresponded mostly with transformation classes of 'residual bare' and 'residual'.

The ecoregions most affected by change ('removed' and 'replaced' transformations) over the years were: the Jezre'el Valley, most affected by 'replaced' transformation, and the Sharon Plain most affected by 'removed' transformation (Figure 4). Indeed, these results are not surprising since the majority of the population is located in these areas as well as many agricultural areas (Figure 1C). In the 19th century most of the human settlements were located in the mountain areas and not in the plains due to the fact that coastal plains and valleys were then more vulnerable security wise (low places were harder to protect) and containing unfertile soil for humans to grow corps (Amiran, 1953; Karmon, 1960). However, this trend has changed during the last 100 years and today half the population lives in the coastal plain area. The population of the Shefela (area between the Judean Hills and the coast) and the Sharon Plain ecoregions, which also include Tel Aviv metropolitan area, stood at 3.8 million people in 2010 in an area of only 4,276 square kilometers (I.C.B.S., 2010). As a result of land transformation, one of the main hotspots areas in Israel of endangered plant species is the Sharon Plain (Levin & Shmida, 2007).

The 'residual' transformation class was dominant in two main ecoregions, and Mt. Carmel and Galilee. Indeed, during the Mandate Period, the British made several efforts to declare Mt. Carmel and Mt. Meron (in Galilee) as protected areas due to their nature and landscape values (Biger & Liphschitz, 1994; El-Eini, 2004). After the creation of the State of Israel, large parts of Mt. Meron and of Mt. Carmel were designated as nature reserves (Israel Department of Justice, May 2013). Today, Mt. Carmel is a national park and a biosphere reserve (recognized by UNESCO) and is a major reserve that has preserved the Mediterranean landscape (Naveh & Carmel, 2004).

Land cover changes in our study were compared to other case studies from the Mediterranean region, such as Southern Spain (1956-2002) (Symeonakis, Calvo-Cases, & Arnau-Rosalen, 2007), Central Italy (Romano & Zullo, 2014), Southern Turkey (1858-2002) (Doygun & Alphan, 2006) and also to Australia (1778-2000) (Thackway & Lesslie, 2008). We adjusted for the different time spans covered in each of the studies (ranging from 44 years in Spain to 222 years in Australia), by calculating average yearly changes in land cover (assuming constant rate of changes). Israel was found to have relatively rapid land cover changes (in terms of urbanization and transformation to agriculture) (Table 8). From the studies presented in Table 8, it seems that areas experiences greater changes in population density, also experience more rapid land cover changes.

Table 8: Comparison of the changes in the transformation of the landscape into urban and agricultural areas in other countries

Study location	Study area in km²	year of analysis	% difference in major land cover classes		% difference in major land cover classes per year		Population density -people/km²		% population change per year	Reference
			Urban	Agriculture	Urban	Agriculture	Beginning of the study period	End of the study period		
Israel	14,700	1881-2011 (130 years)	12.33	47.56	0.09	0.37	27	816	22.3	This study
Australia	7,682,330	1778-2000 (222 years)	0.12	14.14	0.001	0.064	0.065	2.47	17	Thackway & Lesslie, 2008
Central Italy	50,683	1956-2004 (48 years)	3.82	N/A	0.08	N/A	142	179	0.55	Romano & Zullo, 2014
Xaló River, Southeastern Spain	30,200	1956-2000 (44 years)	0.04	34.62	0.001	0.79	N/A	N/A	N/A	Symeonakis, Calvo-Cases, & Arnau-Rosalen, 2007
Iskenderun, Turkey	60.0	1858-2000 (144 years)	20.50	N/A	0.14	N/A	34	2,652	53	Doygun & Alphan, 2006

CONCLUSION

This article demonstrated that the landscapes of Israel, as depicted by changes on land cover mapping, has changed dramatically since the late 19th century. The land cover classes which increased the most in areas were human dominated ones (agricultural fields, orchards, built-up areas). Slope and rainfall explained part of these changes; however, parts of the changes were also related to different ideological and political trends during the years. Today we can see that the majority of the study area is managed by humans. The ecoregions most affected by drastic changes over the years were the Jezre'el Valley, and the Sharon Plain. The study conducted has shown the significance and present relevance of historical maps for reconstructing past landscapes to understanding the processes and changes which have occurred.

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SUPPLEMENT

Table S1: 38 GIS layers used to compile the present day land cover map

The 'Layer priority' column represents the order in which the layers got a priority over other layers in the process of compilation, with 1 representing the highest priority, and 6 the lowest priority. "Total area covered in km²" column represents the area covered by each GIS layer.

GIS layer region	GIS layer type	Scale	Year	Layer priority (1 representing the highest priority, and 6 the lowest priority)	Total area covered in km²	Reference
Carmel	Natural vegetation classes	1:10,000	1983	1	267.6	(Lahav and Farkash, 1983)
Caesarea	Natural vegetation classes	1:10,000	1993	1	48	(Open Landscape Institute, 1993)
Lakhish	Natural vegetation classes	1:10,000	1994	1	146.6	(Open Landscape Institute, 1994)
Carmel seashore: Neve Iam - Dor	Natural vegetation classes	1:10,000	1996	1	32.1	(Lahav et al., 1996)
Sharon seashore	Natural vegetation classes	1:10,000	1997	1	141.7	(Open Landscape Institute, 1997)
Carmel seashore: Dor – Jaser A-Zarka	Natural vegetation classes	1:10,000	1998	1	26.1	(Lahav and Levin, 1998)
North HaSharon	Natural vegetation classes	1:20,000	1999	1	208.3	(Rudich and Ramon, 1999)
Ramat HaNadiv and its surroundings	Natural vegetation classes	1:50,000	1999	1	467.3	(Lahav et al., 1999)
Carmel seashore: Atlit - Haifa	Natural vegetation classes	1:00,000	2000	1	34	(Lahav and Levin, 2000)
Yad Mordehai	Natural vegetation classes	1:20,000	2000	1	7.7	(Open Landscape Institute, 2000)
Southern Kurkarim area	Natural vegetation classes	1:10,000	2001	1	1196	(Romem and Ramon, 2001)
West Jerusalem	Natural vegetation classes	1:10,000	2001	1	18	(Ramon et al., 2001b)
Kineret seashore and its surroundings	Natural vegetation classes	1:50,000	2001	1	899.9	(Ramon et al., 2001a)
Lahav	Natural vegetation classes	1:10,000	2002	1	178	(Zoer et al., 2002)
Park Britannia	Natural vegetation classes	1:10,000	2006-2005	1	27.1	(Ron et al., 2005 - 2006)
Iatir region	Natural vegetation classes	1:10,000	2006	1	178	(Soler et al., 2006)
Carmel city and surroundings	Natural vegetation classes	1:5,000	2008	1	27.6	(Lahav et al., 2008)
East Poleg hills	Natural vegetation classes	1:10,000	2009	1	73.8	(Mendelson et al., 2009)
Palmahim	Natural vegetation classes	1:10,000	2009	1	72.9	(Gal et al., 2008)

GIS layer region	GIS layer type	Scale	Year	Layer priority (1 representing the highest priority, and 6 the lowest priority)	Total area covered in km²	Reference
Naftali ridges mountains	Natural vegetation classes	1:10,000	2009	1	123.3	(Perlberg et al., 2009)
Park Ya'ar Shoham	Natural vegetation classes	1:10,000	2010	1	1.8	(Gal et al., 2010)
Beer Sheva and its surroundings	Natural vegetation classes	1:10,000	2011	1	106.2	(Cohen et al., 2011)
East Rehovot	Natural vegetation classes	1:10,000	2011	1	9.5	(Mendelson, 2011)
Plugot and its surroundings	Natural vegetation classes	1:10,000	2011	1	29.2	(Gal et al., 2011a)
Zafit	Natural vegetation classes	1:10,000	2011	1	181.2	(Gal et al., 2011b)
South-West Galilee	Natural vegetation classes	1:5,000	2012	1	82.9	(Arad and Ramon, 2012)
Kineret slopes - Yavniel	Natural vegetation classes	1:10,000	2012	1	123.1	(Romem et al., 2012)
The Jordan river and its surroundings	Natural vegetation classes	1:10,000	2012	1	114.5	(Gal and Perlberg, 2012)
Lev Hasharon	Natural vegetation classes	1:25,000	2012	1	57.3	(Mendelson et al., 2012)
Shikma river	Natural vegetation classes	1:10,000	2004	2	378.9	(Ramon et al., 2004)
Israel	Water bodies layer	1:2,500	2010	2	66	(Survey of Israel, 2012)
Israel	Agricultural layer	1:2,500	2010	2	6388.7	(Survey of Israel, 2010)
Israel and West Bank	Built-up areas	1:50,000	2003	3	1010.8	(Kaplan, 2003)
West Bank	Land cover	unknown	2006	3	3902.2	(The Applied Research Institute Jerusalem, 2006)
Gaza Strip	Built-up area	1:50,000	2009	4	191	(Levin and Duke, 2012)
Israel, West Bank and Gaza Strip	Digitized layer of several no data areas	1:20,000	2013	4	0.0005	The layer was created within this present study
Israel	Planted forests and maquis	1:2,500	2003	5	811.4	(Jewish National Fund, 2003)
Israel	Natural vegetation classes	1:50,000	1992-1996	6	8922	(Sabah, 1992-1996)

Table S2: The number of patches, total and mean area (in square kilometers) of each land cover class

*N/A in the table means that this class does not exist due to: 1. Not subject focus of the map; 2. Class included in another wider class due to generalization of the classes. **Oak forest – the present distribution of oak trees and forests were generalized and are found under 'maquis' class. *** Planted forest - many of which are 'fir trees'.

Land cover classes	PEF map (1881)			Present map (2011)		
	Number of patches in each class	Total area of classes in km²	Mean patch area in km²	Number of patches in each class	Total area of classes in km²	Mean patch area in km²
Agricultural field	N/A*	N/A	N/A	23614	4409.7	0.19
Alluvial sands	53	25.9	0.49	N/A	N/A	N/A
Artificial water bodies	N/A	N/A	N/A	1656	79.1	0.05
Built area	752	24.2	0.02	14077	1758.3	0.12
Desert shrub steppe	N/A	N/A	N/A	960	1793.6	1.8
Fir trees	101	2.8	0.03	2013	330.7	0.16
Gardens	146	66.2	0.45	312	21.9	0.07
Garrigue	999	960.7	1	3807	391.2	0.10
Maquis	1205	909.8	0.75	4117	1106.7	0.27
Marsh land	50	83.6	1.7	143	5.5	0.04
No data	N/A	N/A	N/A	6234	209.9	0.03
Oak forest**	9	109.1	12.1	N/A	N/A	N/A
Open space	643	11446.9	17.8	N/A	N/A	N/A
Orchards	3846	596.9	0.16	25070	2564.9	0.10
Palm trees	66	3.9	0.06	N/A	N/A	N/A
Planted forest***	N/A	N/A	N/A	4513	264.4	0.06
Riparian vegetation	122	63.6	0.52	1510	26.7	0.02
Sand dunes	28	314	11.2	469	234.1	0.50
Shrub steppe	N/A	N/A	N/A	13740	1386.4	0.10
Traces of oak forest	2	27.2	13.6	N/A	N/A	N/A
Tree	163	1.9	0.01	N/A	N/A	N/A
Vegetated dunes	72	42.5	0.59	424	28.9	0.07
Vineyards	35	23.8	0.68	1893	93.8	0.05
Winter pond	113	14.2	0.13	50	4.2	0.08

Table S3: Transition matrix table showing the transition (in square kilometers) of the land cover classes in two time periods: 1881, 2011.

	Land cover classes 2011 (in km²)									
Land cover classes 1881	agricultural field	artificial water bodies	built area	desert shrub steppe	fir trees	gardens	garrigue	maquis	marsh land	no data
alluvial sands	2.4	0.1	0.3	13.1	0.0	0.0	0.1	0.0	0.0	0.3
built area	2.7	0.0	13.0	0.1	0.3	0.2	0.5	0.9	0.0	0.2
fir trees	0.1	0.0	0.4	0.0	0.0	0.0	0.1	0.9	0.0	0.0
gardens	12.2	0.1	34.7	0.2	0.0	0.0	1.0	0.2	0.0	1.9
garrigue	124.6	1.1	72.4	3.8	47.2	0.7	57.7	252.0	0.1	6.7
maquis	120.6	0.7	82.2	18.9	41.9	0.8	66.1	248.9	0.0	10.1
marsh land	47.5	3.5	8.9	1.1	0.0	0.0	1.8	0.7	0.5	1.1
oak forest	39.3	0.3	45.2	0.0	0.0	0.2	0.1	0.0	0.0	0.2
open space	3931.2	62.8	1221.4	1736.6	230.7	16.0	252.5	557.5	1.8	140.9
orchards	70.0	0.6	94.6	3.7	8.6	3.5	7.7	33.5	0.0	6.8
palm trees	1.2	0.1	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
riparian vegetation	20.2	0.8	4.4	6.6	0.0	0.0	3.0	1.0	0.0	0.3
sand dunes	14.1	7.3	126.9	0.0	0.0	0.5	0.6	2.6	1.3	7.4
traces of oak forest	4.1	0.0	17.1	0.0	0.0	0.0	0.0	0.0	0.0	5.9
tree	0.4	0.0	0.2	0.0	0.1	0.0	0.1	0.2	0.0	0.1
vegetated dunes	3.6	1.9	16.2	0.0	0.0	0.0	0.3	4.3	0.3	0.2
vineyards	3.8	0.0	8.7	0.1	0.0	0.0	0.4	1.3	0.0	0.0
winter pond	3.4	1.0	1.0	0.0	0.0	0.0	0.0	0.2	1.4	0.6
Total km² 2011	4401.5	80.2	1749.8	1784.2	329.0	21.8	392.0	1104.0	5.5	182.7
Total % 2011	28.7	0.6	13.3	13.2	2.4	0.2	3.4	8.1	0.0	1.6

	Land cover classes 2011 (in km²)									
Land cover classes 1881	orchards	planted forests	riparian vegetation	sand dunes	shrub steppe	vegetated dunes	vineyards	winter pond	**Total km² 1881**	**Total % 1881**
alluvial sands	0.9	0.3	0.2	0.1	0.4	0.0	0.0	0.0	18.2	0.2
built area	3.7	0.6	0.0	0.1	1.1	0.0	0.1	0.0	23.6	0.2
fir trees	1.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	2.8	0.0
gardens	12.3	0.5	0.0	2.1	0.8	0.0	0.3	0.0	66.3	0.5
garrigue	230.7	11.1	0.5	0.0	143.0	0.0	6.7	0.0	958.5	6.5
maquis	204.2	24.3	0.7	0.0	84.0	0.0	3.9	0.0	907.3	6.2
marsh land	6.3	0.7	0.7	0.5	0.5	0.3	0.1	0.0	74.1	0.6
oak forest	21.6	1.5	0.0	0.0	0.4	0.1	0.0	0.0	109.0	0.7
open space	1759.3	214.3	21.3	30.9	1089.2	4.3	80.0	3.8	11354.6	77.8
orchards	296.5	5.6	0.3	4.5	57.2	0.0	2.0	0.0	595.0	4.1
palm trees	0.3	0.0	0.0	0.1	0.0	0.0	0.0	0.0	3.9	0.0
riparian vegetation	3.5	0.1	0.3	0.1	0.6	0.0	0.1	0.0	40.9	0.4
sand dunes	14.7	5.4	1.0	114.3	0.2	17.2	0.1	0.4	313.9	2.1
traces of oak forest	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	27.3	0.2
tree	0.4	0.0	0.0	0.0	0.3	0.0	0.0	0.0	1.8	0.0
vegetated dunes	1.0	1.0	1.9	7.4	0.0	4.3	0.1	0.0	42.5	0.3
vineyards	7.0	0.0	0.0	0.0	1.3	0.0	1.1	0.0	23.8	0.2
winter pond	3.2	0.3	0.0	0.0	0.0	0.0	0.0	0.0	11.2	0.1
Total km² 2011	2566.9	265.6	27.1	160.1	1379.2	26.3	94.4	4.2		
Total % 2011	14.5	1.9	0.2	1.0	10.7	0.2	0.0	0.1		

Table S4: Transition matrix table showing the land cover classes of the past and their transition to present day land cover classes (in percentages).

	Land cover classes 2011 (in percentage)									
Land cover classes 1881	agricultural field	artificial water bodies	built area	desert shrub steppe	fir trees	gardens	garrigue	maquis	marsh land	no data
alluvial sands	13.1	0.4	1.7	71.8	0.2	0.0	0.3	0.0	0.0	1.5
built area	11.5	0.0	55.0	0.6	1.4	0.8	2.0	3.7	0.0	0.9
fir trees	3.2	0.0	16.0	0.0	0.4	0.0	4.9	32.7	0.0	0.0
gardens	18.5	0.1	52.4	0.2	0.0	0.1	1.5	0.3	0.0	2.8
garrigue	13.0	0.1	7.6	0.4	4.9	0.1	6.0	26.3	0.0	0.7
maquis	13.3	0.1	9.1	2.1	4.6	0.1	7.3	27.4	0.0	1.1
marsh land	64.1	4.7	12.0	1.5	0.0	0.0	2.5	0.9	0.7	1.5
oak forest	36.0	0.3	41.5	0.0	0.0	0.2	0.1	0.0	0.0	0.2
open space	34.6	0.6	10.8	15.3	2.0	0.1	2.2	4.9	0.0	1.2
orchards	11.8	0.1	15.9	0.6	1.4	0.6	1.3	5.6	0.0	1.1
palm trees	30.5	2.0	50.5	0.8	0.0	0.0	0.3	0.1	0.1	2.3
riparian vegetation	49.4	2.1	10.7	16.1	0.0	0.0	7.4	2.3	0.0	0.8
sand dunes	4.5	2.3	40.4	0.0	0.0	0.1	0.2	0.8	0.4	2.4
traces of oak forest	14.9	0.0	62.8	0.0	0.0	0.0	0.0	0.0	0.0	21.5
tree	20.1	0.0	12.6	1.9	6.4	0.0	2.9	10.2	0.0	3.8
vegetated dunes	8.5	4.4	38.2	0.0	0.0	0.0	0.7	10.2	0.7	0.4
vineyards	16.1	0.0	36.7	0.3	0.1	0.0	1.7	5.4	0.0	0.1
winter pond	30.9	8.8	8.7	0.0	0.0	0.0	0.3	1.5	12.5	5.2

	Land cover classes 2011 (in percentage)								
Land cover classes 1881	orchards	planted forests	riparian vegetation	sand dunes	shrub steppe	vegetated dunes	vineyards	winter pond	**Total % 1881**
alluvial sands	5.1	1.5	1.3	0.5	2.4	0.0	0.0	0.0	100
built area	15.9	2.4	0.2	0.5	4.7	0.1	0.5	0.0	100
fir trees	38.3	1.2	0.0	0.0	3.2	0.0	0.0	0.0	100
gardens	18.5	0.8	0.0	3.2	1.2	0.0	0.4	0.0	100
garrigue	24.1	1.2	0.1	0.0	14.9	0.0	0.7	0.0	100
maquis	22.5	2.7	0.1	0.0	9.3	0.0	0.4	0.0	100
marsh land	8.5	0.9	0.9	0.7	0.7	0.4	0.1	0.0	100
oak forest	19.9	1.3	0.0	0.0	0.4	0.1	0.0	0.0	100
open space	15.5	1.9	0.2	0.3	9.6	0.0	0.7	0.0	100
orchards	49.8	0.9	0.0	0.8	9.6	0.0	0.3	0.0	100
palm trees	9.0	0.2	0.6	2.8	0.5	0.3	0.0	0.0	100
riparian vegetation	8.6	0.2	0.6	0.2	1.4	0.0	0.2	0.0	100
sand dunes	4.7	1.7	0.3	36.4	0.1	5.5	0.0	0.1	100
traces of oak forest	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100
tree	20.5	2.2	1.4	2.5	15.7	0.0	0.0	0.0	100
vegetated dunes	2.3	2.2	4.5	17.4	0.0	10.2	0.2	0.0	100
vineyards	29.4	0.0	0.0	0.0	5.6	0.0	4.5	0.0	100
winter pond	28.4	2.5	0.2	0.3	0.3	0.3	0.1	0.0	100

Table S5: Transition matrix table shows present day land cover classes and from which past land cover classes did they derive from (in percentages)

	Land cover classes 2011 (in percentage)									
Land cover classes 1881	agricultural field	artificial water bodies	built area	desert shrub steppe	fir trees	gardens	garrigue	maquis	marsh land	no data
alluvial sands	0.1	0.1	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.1
built area	0.1	0.0	0.7	0.0	0.1	0.8	0.1	0.1	0.0	0.1
fir trees	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
gardens	0.3	0.1	2.0	0.0	0.0	0.2	0.3	0.0	0.0	1.0
garrigue	2.8	1.4	4.1	0.2	14.4	3.4	14.7	22.8	1.1	3.7
maquis	2.7	0.9	4.7	1.1	12.7	3.5	16.9	22.5	0.0	5.5
marsh land	1.1	4.3	0.5	0.1	0.0	0.0	0.5	0.1	9.2	0.6
oak forest	0.9	0.4	2.6	0.0	0.0	0.8	0.0	0.0	0.8	0.1
open space	89.3	78.3	69.8	97.3	70.1	73.3	64.4	50.5	32.9	77.1
orchards	1.6	0.7	5.4	0.2	2.6	15.9	2.0	3.0	0.0	3.7
palm trees	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0
riparian vegetation	0.5	1.1	0.3	0.4	0.0	0.0	0.8	0.1	0.2	0.2
sand dunes	0.3	9.1	7.3	0.0	0.0	2.1	0.2	0.2	24.5	4.1
traces of oak forest	0.1	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2
tree	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
vegetated dunes	0.1	2.3	0.9	0.0	0.0	0.0	0.1	0.4	5.7	0.1
vineyards	0.1	0.0	0.5	0.0	0.0	0.0	0.1	0.1	0.0	0.0
winter pond	0.1	1.2	0.1	0.0	0.0	0.0	0.0	0.0	25.5	0.3
Total % 2011	100	100	100	100	100	100	100	100	100	100

	Land cover classes 2011 (in percentage)							
Land cover classes 1881	orchards	planted forests	riparian vegetation	sand dunes	shrub steppe	vegetated dunes	vineyards	winter pond
alluvial sands	0.0	0.1	0.9	0.1	0.0	0.0	0.0	0.0
built area	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.0
fir trees	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
gardens	0.5	0.2	0.1	1.3	0.1	0.0	0.3	0.0
garrigue	9.0	4.2	1.9	0.0	10.4	0.0	7.1	0.2
maquis	8.0	9.2	2.7	0.0	6.1	0.0	4.1	0.0
marsh land	0.2	0.2	2.5	0.3	0.0	1.1	0.1	0.2
oak forest	0.8	0.5	0.0	0.0	0.0	0.4	0.0	0.0
open space	68.5	80.7	78.7	19.3	79.0	16.5	84.7	90.6
orchards	11.6	2.1	1.0	2.8	4.1	0.1	2.1	0.4
palm trees	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0
riparian vegetation	0.1	0.0	1.0	0.0	0.0	0.0	0.1	0.0
sand dunes	0.6	2.0	3.7	71.4	0.0	65.2	0.1	8.7
traces of oak forest	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tree	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
vegetated dunes	0.0	0.4	7.1	4.6	0.0	16.4	0.1	0.0
vineyards	0.3	0.0	0.0	0.0	0.1	0.0	1.1	0.0
winter pond	0.1	0.1	0.1	0.0	0.0	0.1	0.0	0.0
Total % 2011	100	100	100	100	100	100	100	100

Fig. S1: Slope classes within the study area

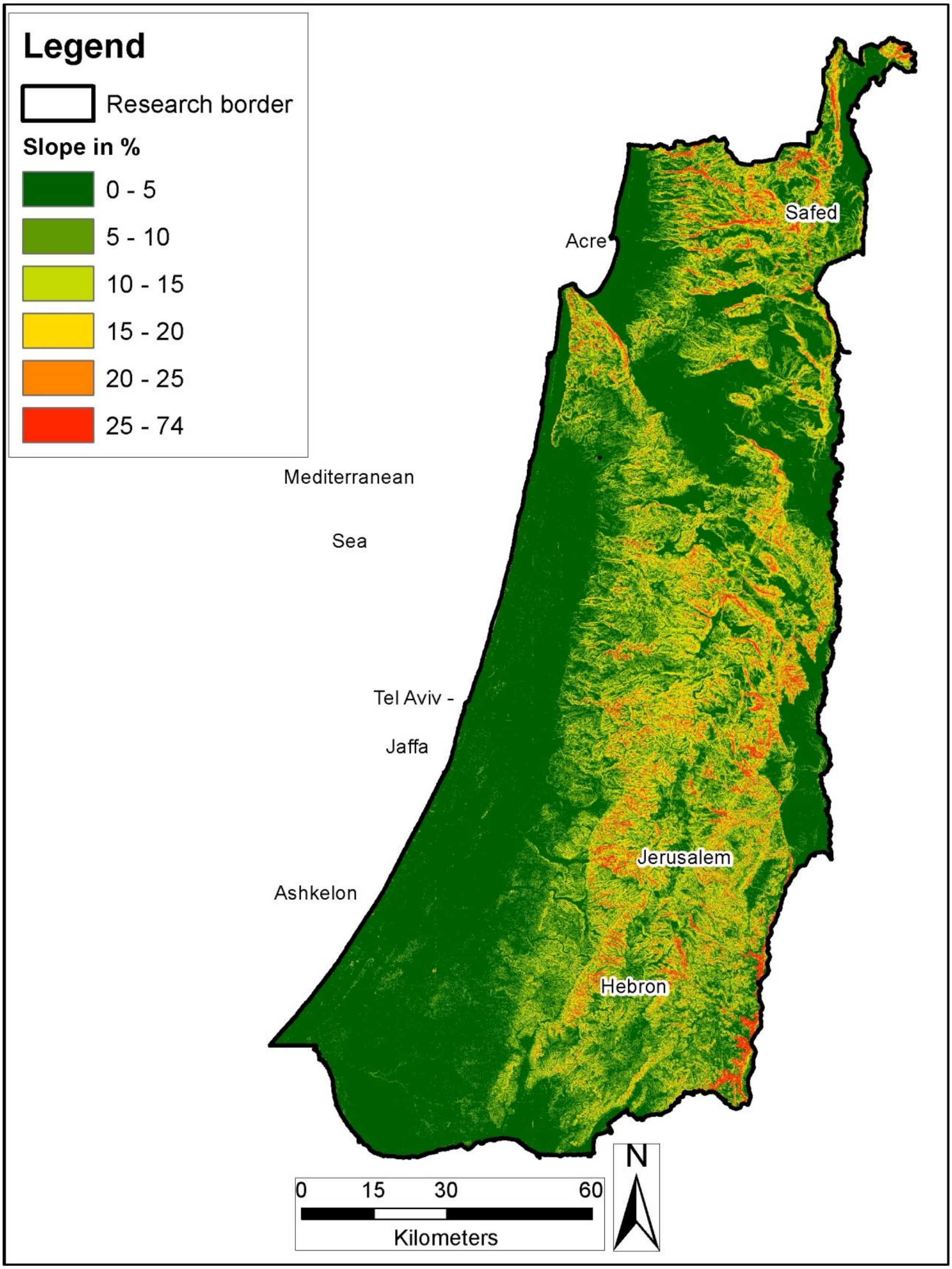

Fig. S2: Map representing the yearly average rainfall in millimeters