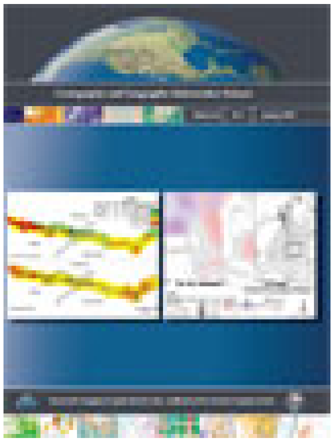



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# Quantifying the completeness of and correspondence between two historical maps: a case study from nineteenth-century Palestine

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# Quantifying the completeness of and correspondence between two historical maps: a case study from nineteenth-century Palestine

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Reconstructing past landscapes from historical maps requires quantifying the accuracy and completeness of these sources. The accuracy and completeness of two historical maps of the same period covering the same area in Israel were examined: the 1:63,360 British Palestine Exploration Fund map (1871–1877) and the 1:100,000 French Levés en Galilée (LG) map (1870). These maps cover the mountainous area of the Galilee (northern Israel), a region with significant natural and topographical diversity, and a long history of human presence. Land-cover features from both maps, as well as the contours drawn on the LG map, were digitized. The overall correspondence between land-cover features shown on both maps was 59% and we found that the geo-referencing method employed (transformation type and source of control points) did not significantly affect these correspondence measures. Both maps show that in the 1870s, 35% of the Galilee was covered by Mediterranean maquis, with less than 8% of the area used for permanent agricultural cropland (e.g., plantations). This article presents how the reliability of the maps was assessed by using two spatial historical sources, and how land-cover classes that were mapped with lower certainty and completeness are identified. Some of the causes that led to observed differences between the maps, including mapping scale, time of year, and the interests of the surveyors, are also identified.

**Keywords:** GIS; historical maps; accuracy; completeness; geo-referencing



## Introduction

For many years, historical maps were not considered as a useful source for research because they were deemed subjective and unreliable (Koeman 1968). However, in recent years there has been a gradual rise in the use of historical maps to examine and reconstruct past landscapes (Kienast 1993; Gregory et al. 2002; Levin 2006; Grossinger et al. 2007; Haase et al. 2007; Levin, Elron, and Gasith 2009; Levin, Kark, and Galilee 2010; Hopkins, Morgan, and Roberts 2011). The increase in the use of historical maps came both from the understanding that maps contain valuable information about the past, and from the introduction of geographical information systems (GIS) software programs, which enable researchers to collect data, analyze it quantitatively, and track changes over time (Knowles 2002; Gregory and Healey 2007). One of the prerequisites for reconstructing past landscapes from historical maps is to first examine their accuracy and completeness (Cousins 2001; Petit and Lambin 2002; Vuorela, Alho, and Kalliola 2002; Hall et al. 2003; Wilson 2005; Leyk and Zimmermann 2007; Podobnikar 2009; Tucci, Giordano, and Ronza 2010; Williams and Baker 2010; Lukas 2014).

Errors in historical maps may have been introduced during field survey due to the short period in which the survey was conducted, physical-topographical obstacles of the surveyed area that made it difficult to measure correctly due to the surveying technology available at the time, measurement errors, and human mistakes (Harley 1968; Beard 1989; Thapa and Bossler 1992; Turnbull 1996). Errors may also have been made during the process of drawing and reproducing the map; for example, omitting information from the map deemed irrelevant to the survey's purpose. Lastly, errors may have occurred during the process of map scanning, geo-referencing, and digitization using GIS tools and methods (Beard 1989; Leyk, Boesch, and Weibel 2005). Errors in historical maps can be divided into two major types: errors related to well-defined features and errors related to poorly defined features (Fisher 1999). Errors of well-defined features (i.e., built-up areas) can be associated with the geometric accuracy of the drawn features, the generalization and simplification in which they were drawn on the map, or with their attributes (Plewe 2002; Tucci and Giordano 2011). Errors of poorly defined features (i.e., natural vegetation features, soil types), whose boundaries are not easy to identify or delineate, are associated with vagueness and ambiguity, and may be open to different interpretation (Fisher 1999; Tucci and Giordano 2011). When mapping or digitizing a map, for example, there are inherent problems such as where to delineate the

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boundary separating two land-cover classes, especially when these classes are natural vegetation features with fuzzy boundaries (Berman 2005). The acknowledgment of these errors and uncertainties is important as they greatly influence our ability to use those maps for reconstructing past landscapes.

Often, research papers that examine and reconstruct past landscapes mainly use a single historical map from a certain period and compare it to other historical sources, such as literary sources, aerial photos, maps, satellite images, and GIS layers from later periods. In several studies, historical maps that were created during the same period and covering the same area were examined. In a study of the Triglav National Park (Slovenia), Podobnikar and Kokalj (2006) examined historical maps of the same area produced by various governments during the 1930s; they noted the differences in the symbology used in these maps, but did not evaluate the correspondence between these maps.

Indeed, in the past there was greater variation between topographic maps with regard to the features and symbols used (Collier, Pearson, and Forrest 1998; Collier, Forrest, and Pearson 2003). A study by Davie and Frumin (2007) examined two historical maps of Beirut from the years 1772 and 1773. Each map was used to fill in the gaps found on the other map and in this way a 3D visualization of the city was reconstructed. In a study by Bower (2011) that examined two maps of England and Wales of the same period, it was determined that the two maps were not independently drawn, based on their geometric distortions. The comparison of two or more historical maps can be very useful, as it allows verifying the existence of landscape features using two independent sources. A greater correspondence between two or more historical sources enables us to reduce uncertainties in reconstructing past land cover (Lukas 2014).

During the nineteenth century, there was a renewal of Western interest in Palestine, and European countries sent military and academic personnel to depict Palestine's landscape and investigate its geography for political, historical, economic, and military purposes (Ben-Arieh 1979). Two valuable maps dating from the 1870s cover the past landscape of the Galilee, which is located in present-day northern Israel (Figure 1). The first historical map we examined is the British Palestine Exploration Fund Survey of Western Palestine (termed PEF in this article for short). The PEF map was made in 1871–1877 by surveyors from the British Royal Engineer Corps appointed by the Palestine Exploration Fund, a British research society (Conder and Kitchener 1871–1877; Conder et al. 1881). The second historical map examined here is the Levés en Galilée (termed LG in this article for short) (trans. Surveys in Galilee), was made in 1870 by two French military captains, Jean-Joseph Mieulet and Isidore Antoine

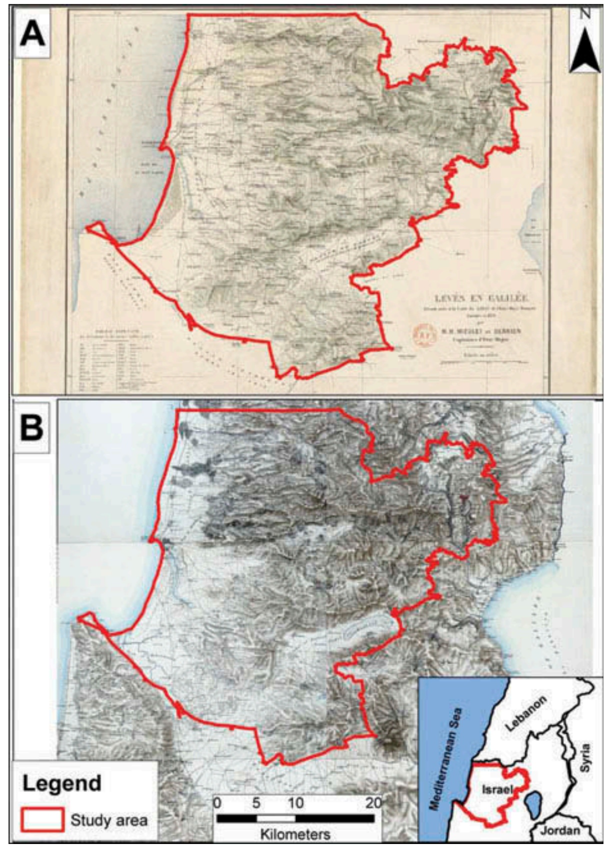


Figure 1. Study area (area enclosed by the red line) on the Levés en Galilée map (a) and on the Palestine Exploration Fund map (b).

Michel Derrien (Mieulet and Derrien 1870; Gavish 1991, 1994). Both maps show land-cover classes and topography. Several past studies have used the PEF map for depicting the nineteenth-century landscape of Palestine and used parts of it for other research interests (Margalit 1955; Schick 1955; Levin 2006; Levin, Elron, and Gasith 2009; Schaffer and Levin 2014). However, the LG map was only described and examined qualitatively by Gavish (1991, 1994).

Having access to two historical maps, created independently at the scale of topographic mapping, the main intention of this research was to examine various indicators of correspondence between land-cover features extracted from historical maps and to explore some of the factors affecting their correspondence. More specifically, the three aims of this research were:

- To evaluate the effects of the geo-referencing method that is employed to estimate the accuracy of a historical map by comparing various geo-referencing schemes.

- To examine the completeness and correspondence of land-cover information represented on the LG and PEF maps by comparing them to each other.
- To evaluate the geometric and elevation accuracy of the LG map by examining the LG elevation data with a present-day digital elevation model.

## Methods

### Study area

The area of the Galilee region (present-day northern Israel) examined here covered 138,900 hectares (Figure 1). The Galilee region is divided into two geographical parts, the Lower Galilee, which is dominated by hills and mountains ranging between 200 and 900 meters, and the Upper Galilee, which is dominated by higher mountains ranging between 700 and 1200 meters. The Galilee has a Mediterranean climate with an average annual rainfall of 900–1200 millimeters, and a dry and hot summer season (Waisel, Pollak, and Cohen 1978). The Galilee is a region with significant natural and topographical value, including several large protected areas, one of which is Mount Meron (1208 meters high).

### Study sources

This research is based on two main historical sources. The first source is the PEF survey between the years 1871–1877 (Conder and Kitchener 1871–1877). Although we do not know how long it took the PEF surveyors to investigate the study area, we do know that most of the study area was surveyed in 1877, with certain areas in the southern part of the study area surveyed in 1875 (Conder and Kitchener 1871–1877). The scale of the PEF map is 1:63,360 and it shows various landscape features, and uses shading to depict the topography. This map was scanned by the National Library of Israel (http://www.jnul.huji.ac.il/dl/maps/pal/html/) at a resolution of 300 dpi, a resolution that does not allow the application of semiautomatic vectorization methods (for which maps should be scanned at a resolution of at least 600 dpi). The PEF map was geo-referenced by Levin (2006) using 123 control points of triangulation stations and a first-order polynomial, with a root mean squared error of 74.4 meters and a median error of all control and test points ($n$ = 1104) amounting to 153.6 meters (2.4 millimeters error on the map). The PEF map is acclaimed for its precision and accuracy, and is the best available nineteenth-century map of Palestine (Hodson 1997; Levin 2006).

The second main historic source in our study is titled “Levés en Galilée, faisant suite à la carte du Liban de l'état-major français’,” which was surveyed between May and August of 1870 (Mieulet and Derrien 1870). The aim of these two officers was to construct a new map of Palestine; however, they were recalled to France at the outbreak of the war with Germany (Maunoir, Cortambert, and Delamarre 1871). We obtained a scanned version (at 300 dpi) of the LG map from the National Library of France (Bibliothèque Nationale de France, Département Cartes et Plans, GE C-2112). The scale of the LG map was 1:100,000 and it shows various landscape features, including contour lines at vertical intervals of 20 meters. Both maps depict the landscape in great detail, and include built-up areas and various natural features (Appendix Figure A1).While the LG map does not include a legend, the PEF map has a detailed legend and is also accompanied by three memoirs (Conder et al. 1881) that describe the map in detail, as well as a book on the flora and fauna of Palestine (Tristram 1884). We used additional spatial data sets that included a contour layer of Israel (SOI 2009) to generate an accurate present-day digital elevation model.

### Spatial analysis

The research was divided into five steps as shown in Figure 2 and as described in the following sections.

#### *Geo-referencing of LG map*

When analyzing historical maps, errors may result from various sources related to the map production stage (i.e., field survey) and the data processing of the map within GIS; for example, geo-referencing or incorrect interpretation of the map during digitization (Leyk, Boesch, and Weibel 2005). For the purpose of analyzing the possible impact of the geo-referencing process on our estimates of map correspondence and completeness, we geo-referenced the LG map to the Israel Transverse Mercator (ITM) GRS80 projection in four different ways. Two sets of ground control points (GCPs) were used to geo-reference the LG map: 145 GCPs were collected from present-day 1:50,000 topographical maps of the Survey of Israel, and 115 GCPs were collected from the PEF map (Appendix Figure A2). The difference in the number of GCPs between the two sets arose because there were fewer shared control points in the PEF map than in the present-day 1:50,000 maps. The GCPs included triangulation points, elevation points and several river intersections, ancient tombs and corners in the old city walls of Acre. Two transformation types were applied to each of the GCPs data sets: a global first-order polynomial

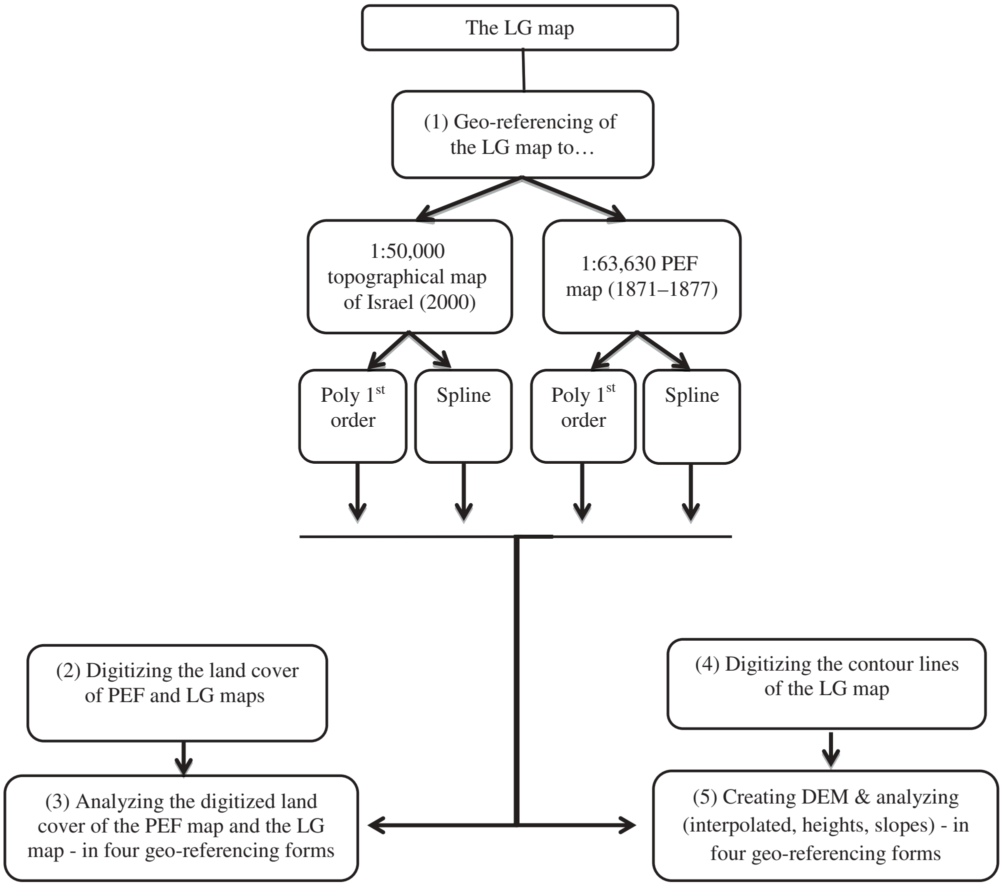


Figure 2. Conceptual diagram showing the research methodology divided into five steps. The Levés en Galilée (LG) map and the Palestine Exploration Fund (PEF) map.



transformation and a local spline transformation. The advantage of the spline method is that it forces the control points to their exact locations, with differential distortions in different areas of the map (Zitová and Flusser 2003). We used the Global Moran's I autocorrelation test (Moran 1950) to test whether the spatial distribution of the GCPs was random, and we also examined whether the size of the RMSE of each of the GCPs correlated to the following three variables: elevation, slope, and distance from built-up areas drawn on the French map. We assumed that areas found in high-elevation areas, steep-slope areas, or away from built-up areas could have been mapped less accurately, and as a result, may have a higher RMSE error than areas closer to built-up areas in plain terrain.

### *Digitizing land cover and contours*

As the LG map was not accompanied by a legend, after examining it and other historical maps including the PEF map, we defined nine broad land-cover classes that appeared to represent the drawn features on both the PEF map and LG map (Figure 3). Land-cover features were digitized as polygons from both the PEF and the LG maps at a screen scale of 1:15,000. Where available, the name of drawn built-up areas was added to their attribute table. We estimated the "level of certainty" in identifying the land-cover class of each of the digitized polygons (Grossinger et al. 2007): a definite identification of the class of a feature was marked as 1, a partial identification was marked as 2, and an uncertain identification was marked as 3.

Contour lines shown on the LG map were in intervals of 20 meters from 80 meters below sea level and up to 1160 meters above sea level. The contour lines were digitized by drawing polylines at a screen scale of 1:5000. Elevation values were assigned to the contours based on the topographic layout, their vertical intervals, and elevation points marked on the map.

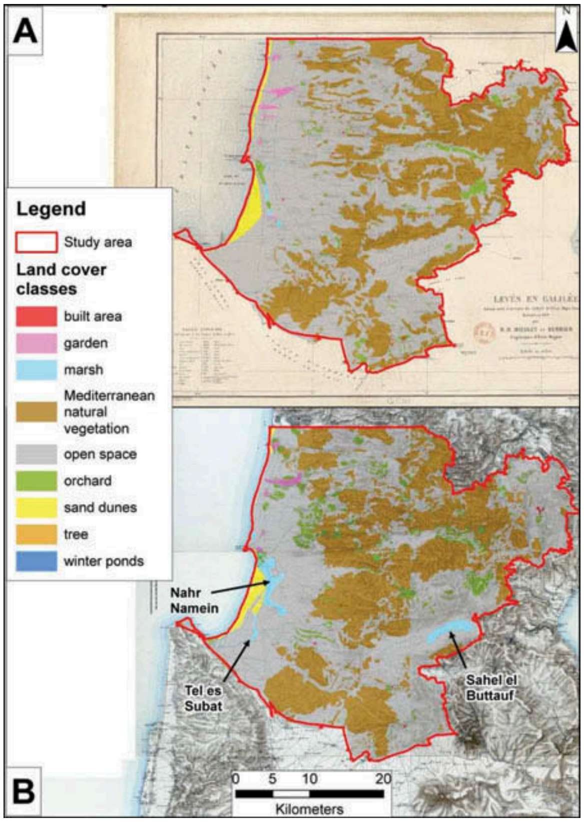


Figure 3. Digitized land-cover/land-use map showing the Galilee area in the nineteenth century as depicted on the Levés en Galilée map (a) and the Palestine Exploration Fund map (b). The arrows indicate major wetlands that appear on the Palestine Exploration Fund map (b).

### *Analyzing the correspondence between the digitized land-cover maps*

To examine the correspondence between the two digitized land-cover maps, we created a confusion matrix between the PEF land cover and the LG land cover. As the LG map was geo-referenced in four different methods, overall four confusion matrices were calculated. From each confusion matrix, we calculated the overall correspondence, as well as the kappa index of agreement (Cohen 1960) using the following equation:

$$\kappa \text{ index of agreement} = \frac{\text{overall accuracy} - \text{chance agreement}}{1 - \text{chance of agreement}} \tag{1}$$

However, the standard $\kappa$ index of agreement is considered inappropriate for map comparison because it does not distinguish between map correspondence due to quantities and map correspondence due to locations of categories on a map (Pontius 2000; Pontius and Millones 2011). Pontius has therefore developed additional indices that can test whether the correspondence between two maps is due to their location of categories or the quantity of these categories. We have thus calculated two additional $\kappa$ indices developed by Pontius (2000, 2002) using the "Validate" module in Idrisi Selva 17.02 (Clark Labs 2012): (1) the $\kappa$ index for location (K-location), indicating the extent to which two maps agree in terms of location of each land-cover class; and (2) the $\kappa$ agreement index due to quantity, which is the additional agreement (beyond the agreement due to chance) between the two maps in terms of the quantity of each land-cover class. To spatially quantify the level of coherence between the five land-cover maps (four times geo-referenced LG map plus the PEF map), we rasterized the maps to a spatial resolution of 50 meters (corresponding to less than 1 millimeter on the hardcopy maps) and overlaid them. If a pixel was assigned to the same land-cover class in all five layers, it received a score of 5 (i.e., strong coherence); if it was assigned to the same land-cover class in four of the five layers, it received a score of 4 and so on.

To study the completeness of information shown on the maps, we examined two cover classes: "built-up areas" and "water bodies" (which includes "winter ponds" and "marsh" lands). These land-cover classes were chosen as they were clearly defined and are composed of countable features with unique names that can be mentioned in written historical sources (Guerin 1868; Conder et al. 1881).

### *Evaluating the topographic accuracy of the LG map*

We interpolated the digitized contours into a digital elevation model (DEM) at a spatial resolution of 25 meters. We used the parabolic interpolation by triangulated irregular network (TIN) (Zhu, Eastman, and Toledano 2001), as implemented in Idrisi Selva GIS software (IDRISI 2012). We compared the LG DEM to a present-day DEM, which we interpolated from present-day contours (derived from aerial photogrammetry) at vertical intervals of 10 meters (vertical and positional accuracy of 2 meters), provided by the Survey of Israel (SOI 2009). From the SOI DEM, we calculated a slope layer. The DEM that was generated from the LG map was geo-referenced four times as described in the section "Analyzing the correspondence between the digitized land-cover maps." We then compared the LG DEM and the SOI DEM, constructing DEMs of difference (DoD), subtracting one elevation model from the other (as in James et al. 2012). We also examined the spatial distribution of the height errors found between the LG DEM and the present-day DEM. We hypothesized that differences in elevation are dependent on the following two factors: slopes and height above sea level. We hypothesized that errors in elevation will increase with height (due to methods used in the past to measure heights) and will increase in rugged areas (due to measurement errors and due to geo-referencing errors) (Collier 1972; Leyk and Zimmermann 2004).

## Results

### *Geo-referencing accuracy of the LG map*

The registration RMSE of the LG map was 250.6 meters (using a first-order polynomial) based on 145 GCPs collected from present-day 1:50,000 topographic maps, and 362.8 meters (using a first-order polynomial) based on 115 GCPs collected from the 1881 1:63,360 PEF map. The spatial distribution of the GCPs was random according to Global Moran's I autocorrelation test ($I$ = 0.034, $p$ = 0.002 for the PEF derived GCPs; $I$ = 0.027, $p$ = 0.026 for the GCPs derived from present-day topographic maps), and the RMSE values of the GCPs were not correlated to the three variables examined (elevation, slope, and distance from built-up areas).

### *Land-cover analysis*

*Analysis of geo-referencing transformation types*

The overall correspondence between the PEF land-cover map and the LG land-cover map (Figure 3) did not vary significantly between the four geo-referencing methods, ranging between 59.07% and 59.65% (Table 1) in the four geo-referencing methods. The $\kappa$ index of agreement ranged between 24.97% and 26.13% (Table 1), the K-location index of agreement ranged between 27.07% and 29.31%, whereas the agreement due to quantity index ranged between 34.62% and 35.60% (Table 1). While these $\kappa$ values are not high, they are commonly interpreted as representing a "fair agreement" (Viera and Garrett 2005).

Table 1. Results of the correspondence between the two digitized land-cover maps, as a function of the employed geo-referencing method.

| Test | Source of the control points | Geo-referencing transformation type: First-order polynomial | Spline |
|---|---|---|---|
| Overall correspondence | PEF map | 59.3% | 59.6% |
| | Israel 1:50,000 map | 59.3% | 59.07% |
| $\kappa$ index of agreement | PEF map | 25.5% | 26.1% |
| | Israel 1:50,000 map | 25.5% | 24.9% |
| K-location | PEF map | 28.8% | 29.3% |
| | Israel 1:50,000 map | 27.9% | 27.07% |
| Agreement due to quantity | PEF map | 34.6% | 35.2% |
| | Israel 1:50,000 map | 35.6% | 35.5% |

The spatial fuzziness in the reconstructed land cover can be appreciated by overlaying the different land-cover layers (Figure 4a). Areas with low coherence (shown in orange and red shades in Figure 4b) were mostly areas on the borders of the study area. Nevertheless, a high level of coherence (levels 4 and 5) was found in most of the maps (81.8%), shown in bright and dark shades of green in Figure 4b. A positive correlation (Spearman's $r$ = 0.783, $p$ = 0.017) was found between the total area of a land-cover class and its average level of coherence (Figure 5). On one hand, the land-cover classes with the largest

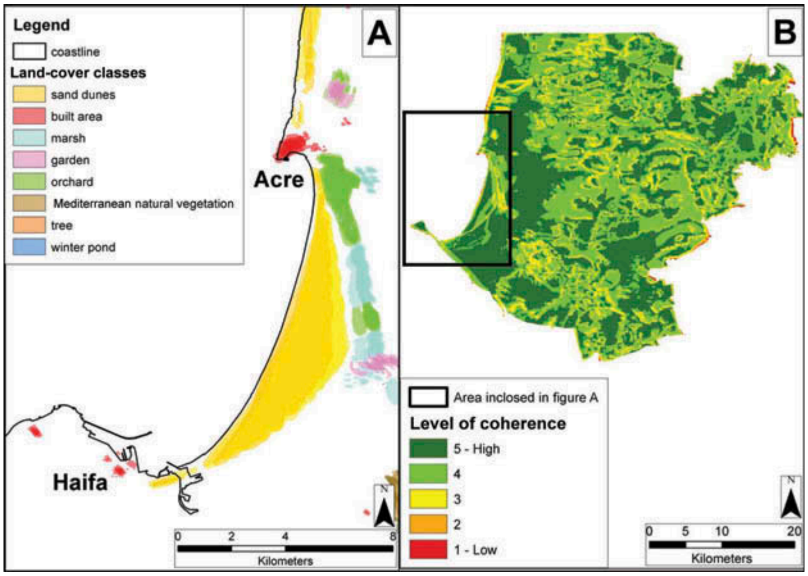


Figure 4. Map representing the fuzziness created when transparently overlaying the land-cover maps derived from the Levés en Galilée map (using each of the four geo-referencing methods) (a). The level of coherence of the land-cover classes (b).

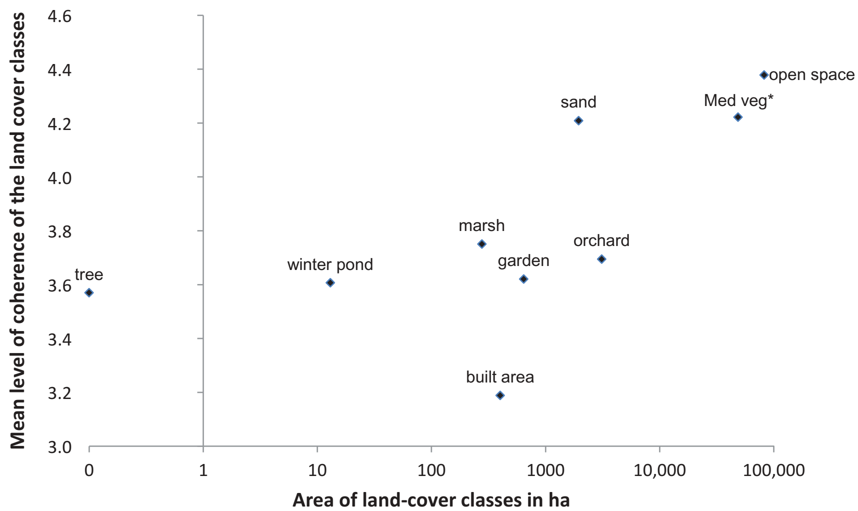


Figure 5. Level of coherence of the land-cover classes that appear on the Levés en Galilée map with respect to their size (*Mediterranean natural vegetation).



area were "open space" with 82,477 hectares (on the LG map) and "Mediterranean natural vegetation" with 48,673 hectares (on the LG map) (Table 2). These two land-cover classes were also the highest in their mean level of coherence with 4.4 for "open space" and 4.2 for "Mediterranean natural vegetation." On the other hand, land-cover classes with a small area on the LG map had a lower level of coherence such as in the case of "built-up area," which had an area of 400 hectares and whose mean level of coherence, 3.2, was relatively low, as well as other small-sized cover classes such as "tree," "winter pond," and "gardens" with a mean coherence level of 3.6. Most of the land-cover features on both the PEF and LG maps were identified with high degree of certainty. Only 6.4% of the land-cover patches on the PEF map and 0.36% of the land-cover patches on the LG map received certainty scores lower than 1 (where 1 equals a high certainty of identification).

*Completeness of thematic information*

The LG map included 116 inhabited "built-up" areas (those that had a "ruin" caption next to the area were not included in this analysis), whereas on the PEF map only 110 inhabited "built-up" areas were drawn. On the LG map, with regard to water bodies, which included both "marsh land" and "winter pond" areas, there were in total 16 water bodies (15 "winter ponds" and one "marsh lands" area), which were drawn as 23 small separate patches; on the PEF map, there were in total 18 water bodies (14 "winter ponds" and four "marsh land" areas).[1]

Regarding the built-up areas found, there were in total 12 discrepancies, with three "built-up" areas appearing on the PEF map that did not appear on the LG map and nine "built-up" areas appearing on the LG map that were depicted as ruins, orchards, or empty areas (open spaces) on the PEF map (Appendix Table A1),

Table 2. The total area (in hectares) and the percentage of the nine cover classes as found on the Levés en Galilée map and on the Palestine Exploration Fund map.

| Land-cover classes | Area in ha on the Leves en Galilee Map | Percentage of the total area of the Leves en Galilee map | Area in ha on the Palestine Exploration Fund map | Percentage of the total area of the Palestine Exploration Fund map |
|---|---|---|---|---|
| Built-up | 399.9 | 0.29 | 334.4 | 0.24 |
| Garden | 644.4 | 0.47 | 590.2 | 0.43 |
| Marsh | 276.9 | 0.20 | 2424.1 | 1.8 |
| Mediterranean natural vegetation | 48,673.9 | 35.4 | 48,118.5 | 35 |
| Open space | 82,477.5 | 60 | 75,270.9 | 54.7 |
| Orchard | 3111.1 | 2.3 | 9379.4 | 6.8 |
| Sand dune | 1950.8 | 1.4 | 1342.1 | 1 |
| Tree | 0.12 | 0.0001 | 20 | 0.01 |
| Winter pond | 12.6 | 0.009 | 8.9 | 0.01 |

Table 3. Number and median size of patches (in hectares) of land-cover classes, digitized from the Levés en Galilée map and from the Palestine Exploration Fund map.

| | Levés en Galilée map | | Palestine exploration fund map | |
|---|---|---|---|---|
| Land-cover classes | Total number of polygons** | Median area of cover classes in ha | Total number of polygons** | Median area of cover classes in ha |
| Built-up area* | 209 | 1.1 | 112 | 2.1 |
| Garden | 9 | 47 | 16 | 9.9 |
| Marsh | 23 | 5.5 | 15 | 16.3 |
| Mediterranean natural vegetation | 143 | 27.2 | 200 | 9.2 |
| Open space | 48 | 21.7 | 85 | 5.5 |
| Orchard | 141 | 7.8 | 677 | 2.3 |
| Sand dunes | 12 | 33.6 | 8 | 39.6 |
| Tree | 1 | 0.12 | 14 | 1.4 |
| Winter pond | 15 | 0.31 | 14 | 0.58 |

Notes: * Built-up areas on the Levés en Galilée map include non-inhabited ruins.
** Some features were created from more than one polygon for each feature.



Regarding the water bodies found, there were 12 discrepancies in total (Appendix Table A2), with nine of the missing water bodies being smaller than one hectare. Two of the three "marsh land" areas appearing on the PEF map that did not appear on the LG maps are large seasonal wetlands. These were "Tel es Subat" (119 hectares) and "Sahel el Buttauf" (813 hectares) (Figure 3, Appendix Table A2). The scale differences between the two maps amount to 1.57 length-wise (PEF scale of 1:63,360 divided by the LG map scale of 1:100,000) and to 2.49 area-wise ($100^2/63.36^2$). Nevertheless, although the scale of the PEF map was more detailed than that of the LG map, in some land-cover classes, the LG map had more patches than the PEF map, and showed smaller patches (Table 3). Our observations confirm that in certain cases smaller scale maps may have more thematic detail than larger scale maps.

### *Analysis of DEM and elevation points*

Figure 6a represents the complete digitization of the contour lines found on the LG. Figure 6b presents the

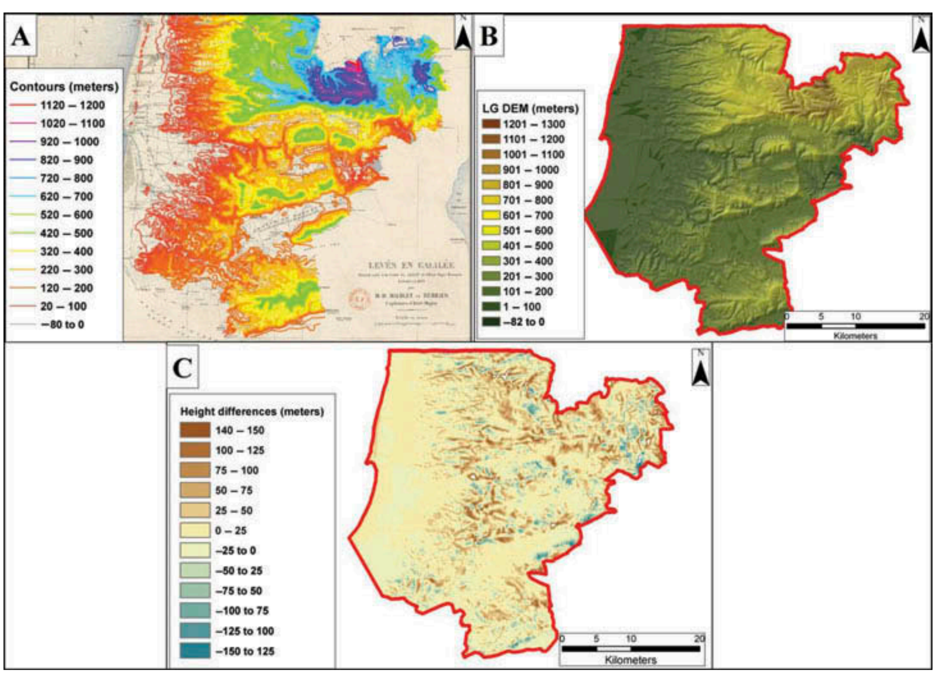


Figure 6. Digitized contours from the Levés en Galilée map (a); The interpolated DEM generated from the digitized contours (b); Height differences map of the comparison made between the Levés en Galilée derived DEM (Figure 6b) and the DEM of Survey of Israel (2009) (c).

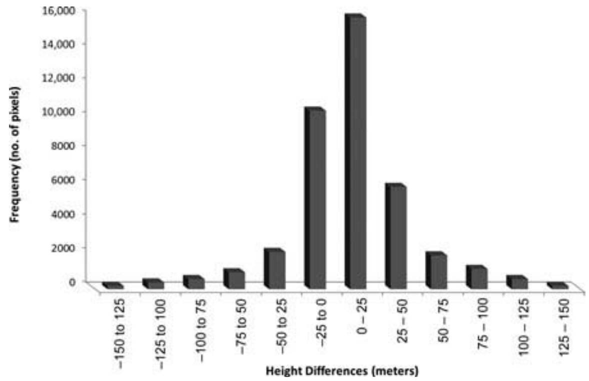


Figure 7. Histogram representing the height differences found between the Levés en Galilée derived DEM and the present-day DEM.

DEM that was interpolated from the LG contours. The differences (i.e., errors) of the heights between the LG-derived DEM and the present-day DEM (Figure 6c) were normally distributed (Figure 7) around a mean of 27.35 meters, with the majority (90.3%) of the elevation differences being less than 50 meters.

The geo-referencing method applied to the LG map did not significantly affect the differences in height (ranging between 26 and 29 meters; Table 4). Since no significant differences were detected between the four geo-referencing methods, for the following regression analysis we used the geo-referenced LG map based on a first-order polynomial and GCPs collected from the 1:50,000 maps.

The results of the spatial autocorrelation test found that elevation errors were spatially clustered (Moran's Index = 0.85, $p < 0.001$). A moderate positive correlation was found between elevation and height differences after a logarithmic transformation of both variables ($r = 0.46$; $p < 0.05$; $n = 2{,}120{,}262$). In a multiple regression test we conducted between two independent variables (slope and height) and the dependent variable (of differences in heights), the adjusted value was $r = 0.53$ (the regressions were run after a logarithmic transformation of all variables).

The height differences were mainly explained by elevation ($t$-test value of 358.6, $p < 0.01$) followed by slope ($t$-test value of 336.6, $p < 0.01$). Thus, the adjusted $r$ value of the multiple regression analysis was slightly higher than those obtained from the single regressions presented above.

To estimate whether the overall differences in height between the LG-derived DEM and the present-day DEM were reasonable, we calculated the following budget error, taking into account: errors related to of the scale of the historical maps, the root mean squared error (RMSE) of the geo-referencing stage, and the pixel size of the DEMs and of the historical map. Consequently (Thapa and Bossler 1992), we assumed that for each source map a planimetric error of 0.81 millimeters can be expected. These errors should be added to errors due to the DEM resolution (25 meters) and the geo-referencing process (RMSE = 362.8 meters). Summing up all these errors resulted in a total expected location error of 374.8 meters (Equation (2)):

$$
\begin{aligned}
&= \sqrt{\sum \left[ \begin{array}{c} (1/\text{scale of reference map}/1000 \times 0.81)^2 + (1/\text{scale of LG map}/1000 \times 0.81)^2 + \text{RMSE}^2 + \\ (\text{resolution of modern DEM})^2 + (\text{resolution of LG DEM})^2 \end{array} \right]} \\
&= \sqrt{[50 \times 0.81]^2 + [100 \times 0.81]^2 + 362^2 + 25^2 + 25^2} = 374.8
\end{aligned} \tag{2}
$$

Table 4. Results of summed absolute differences of the heights found in the four different geo-referencing types. The first number shown is the mean in meters and the number in parentheses is the standard deviation (in meters).

| Control points source | Geo-referencing by PEF | | Geo-referencing by 1:50,000 | |
|---|---|---|---|---|
| Transformation method | *First-order polynomial* | *Spline* | *First-order polynomial* | *Spline* |
| **Survey of Israel DEM** | 26.2 (34.4) | 29.4 (37.3) | 26.09 (35.9) | 26.6 (36.5) |

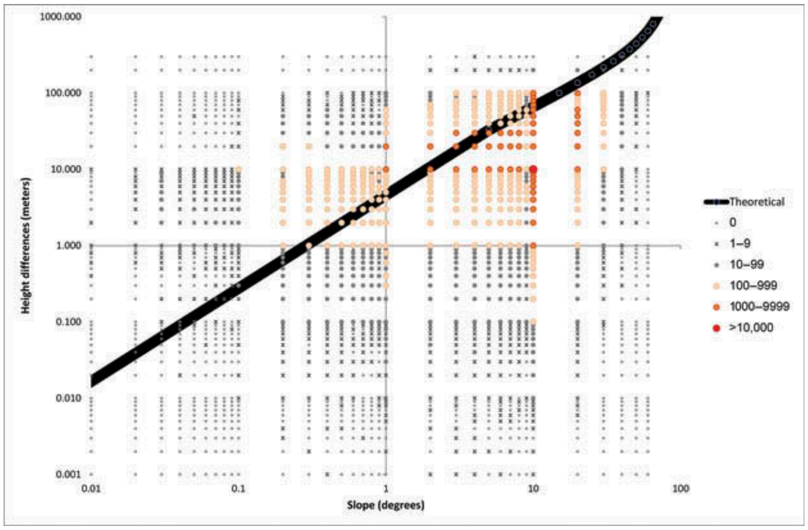


Figure 8. The theoretical (predicted) height differences between the Levés en Galilée derived DEM and the present-day DEM as a function of slope (for a planimetric error of 375 m) are shown along the black line. The distribution of the actual height differences between the two DEMs are shown by the points (colored by their frequency). All points below the black line represent errors that are smaller than the theoretical errors.

As planimetric errors lead to elevation errors (Fisher and Tate 2006), we used the following approach to predict the expected elevation errors: Using basic trigonometry, elevation errors can be predicted for different planimetric location errors and for different slopes (assuming slopes with uniform angle), e.g., for a slope with an angle of 15º and a planimetric error of 375 meters, the resulting vertical error can be predicted to be 100 meters (tan (15º) × 375 = 100). Thus we calculated the theoretical (predicted) height differences as a function of slope (for a planimetric error of 375 meters; Figure 8). The majority (68%) of height differences between the LG-derived DEM and the modern DEM were less than predicted (Figure 8).

## Discussion

### *Geo-referencing accuracy of the maps*

Both the PEF and LG maps were surveyed in the field by professional military surveyors. In the nineteenth century, the tools used to conduct land surveys were an odometer for measuring distances and a prismatic compass for measuring angles (Giordano and Nolan 2007). The surveyors of the LG map chose a location east of Acre, and then continued creating a triangulation network (21 triangulation points in total) from that baseline (Wilson 1873; Gavish 1994). The details were filled in on the same scale with a compass (Hutchinson 1873). After all the information was gathered, the surveyor would sit down and draw the map.

The PEF map we used here was geo-referenced by Levin (2006) using triangulation points drawn on it, with an RMSE of 74 meters, which is only slightly more than 1 millimeter on that map. When more than 1000 test points were examined for their positional accuracy on the PEF map, the RMSE was found to be 272 meters (Levin 2006), i.e., equivalent to about 4.3 millimeters on the PEF map. The LG map did not have many triangulation points drawn on it, so we used additional features (that can be expected to be surveyed less accurately) to geo-reference that map. When the LG map was geo-referenced to 1:50,000 topographical maps, the RMSE was 250.6 meters (about 2.5 millimeters on the map); when the LG map was geo-referenced based on the 1880 PEF map, the RMSE was higher, being 362.8 meters (about 3.6 millimeters on the map). Thus, the overall planimetric accuracy of the LG and the PEF maps was found to be in the order of about 300 meters. An average RMSE of about 300 meters for both maps is not low; however, at the time these surveys were conducted, these maps were the best ones available (Hodson 1997; Levin 2006). Most of the land-cover features with low coherence levels (1 and 2) were found on the borders between the land-cover features or in small-scale patches, covering less than 20% of the total research area on the LG map (Figure 4b).

The scale of the two historical maps is different – the scale of the PEF map was 1:63,360 and the scale of the LG map was 1:100,000. Differences in map scale could potentially increase inaccuracies and errors in the analysis of the landscape, and larger scale maps are often more detailed than smaller scale maps (Levin, Kark, and Galilee 2010). As the PEF map was drawn to a larger scale than the LG map, on the PEF map we expected to find on average more polygons smaller in size than the ones drawn on the LG map. Contrary to this expectation, the results showed no real trend toward more and smaller polygons on the PEF map than on the LG map (Table 3).

The PEF map was based on seven years of field surveys using a compass and cavalry sketching board (Levin 2006). Unlike the Galilee region on the PEF map, which was surveyed in the years of 1875 and 1877, the LG map was surveyed in just three months and had to be conducted at a much faster pace (Gavish 1994). While Close (1932, 146) agrees that the triangulation of PEF map was "quite adequate," he notes that as the "detail was filled in by prismatic compass" and not by using plane-table, it was "somewhat loose." While details on the LG map were also filled in using a compass (Hutchinson 1873), the presence of contour lines on the LG map may indicate the use of more accurate tools and methods than those used on the PEF map.

### *Analyzing the effects of the geo-referencing method of spatial uncertainty*

A wide variety of transformation methods for geo-referencing historical maps is available within GIS software, and users are required to choose the appropriate method based on the type of distortions found on the historical map and the type of analysis undertaken (Boutoura and Livieratos 2006; Levin 2006). Comparing four different geo-referencing schemes (two data sets of control points × two transformation types), we found that the geo-referencing scheme applied, did not alter our estimates of map accuracy significantly, both for correspondence of the land-cover mapping (Table 1) and with regard to the accuracy of the DEM (Table 4). Our finding that the accuracy estimates of the historical maps were not affected by the geo-referencing method may be due to: (1) the large number ($n$ > 100) and the random distribution of the control points throughout the maps; (2) the relatively small RMSE of the historical maps (of about three millimeters on the map scale). In other studies where the mapping accuracy varies throughout the map, local transformations such as the affine or spline methods may be advantageous as they allow locally deforming the historical map so it will better fit its location.

### *Thematic accuracy and completeness of the maps and their information*

The differences found between the two maps can result from two types of errors: the first, a quantity error, which occurs when the total area of a particular land-cover class on one map differs from the total area of that class in the other map; second, a location error, which occurs when the location of a land-cover class on one map does not fit with the location of that land-cover class on the other map (Pontius 2000). Overall, the two maps were in reasonable agreement (59% overall) regarding the past landscape of the study area, with about 55–60% of "open space," 35% of "Mediterranean natural vegetation," and 0.2–0.3% of built-up areas. The agreement due to quantity (35.11% on average) was higher than the agreement due to location (K-location index on average 28.19%). These results support the notion that some of the differences between the two land-cover maps were related to differences in location, which may have been introduced in the surveying, drawing, and digitizing the maps; however, differences in location cannot explain all the differences found between the two maps.

Quantity differences between the two maps may be due to the time of year the survey was conducted. There were significantly more marsh areas shown on the PEF map (2420 hectares) than on the LG map (280 hectares). Indeed, the two large "marsh lands" Sahel el Buttauf and Tel es Subat were completely missing from the LG map, and Nahr Namein "marsh land" was shown on the LG map as several small patches of marsh lands unlike the PEF map, on which it was drawn as one large wetland (see Figure 3). The wetland presently known as the Valley of Netofa (Biq'at Beit Netofa in Hebrew) may still be largely flooded every several years in winters with heavy rainfall. One possible explanation for the difference found regarding the mapped water bodies is that the survey of the LG map was conducted between May and August (the hot and dry summer season), and as a result, many of the water bodies were probably dry. Indeed, on the PEF map it is written "Marsh in Winter" next to Tel es Subat marsh land (Conder and Kitchener 1871–1877). Moreover, if we examine the average annual rainfall of that period, we notice that during the PEF survey in two out of the seven years (the winters of 1873/1874 and of 1877/1878), the average rainfall was above the annual average, in contrast to the annual rainfall in 1870, which was approximately the annual average (Levin, Elron, and Gasith 2009); therefore; it may be expected that the PEF surveyors encountered more wetlands during their field work.

With regard to differences in the mapping of built-up areas between the two maps, there were 12 dissimilarities. Based on the PEF memoirs, it is clear that "built-up areas" (shown as red polygons) on the PEF map refer to inhabited areas (Conder and Kitchener 1871–1877; Conder 1878; Conder et al. 1881); however, while many of the "built-up areas" (shown as red dots) on the LG map were small villages and towns, some were actually ruins (named on the map as Kh. or Kharbet, the Arabic term for *ruin*). Indeed, one of the aims of the French surveyors was to identify ancient and medieval sites (Dussaud 1925). As the LG map did not have a legend, it was concluded that unlike the PEF map, the LG map marked all the buildings found and not necessarily just the inhabited "built-up areas." After omitting from our analysis all the areas named as ruins on the LG map, we reexamined our results. As shown in Appendix Table A1, we found that there were three "built-up areas" (shown on the PEF map) that did not appear on the LG map, and that there were nine "built-up areas" (shown on the LG map) that did not appear on the PEF map. Four of the missing built-up areas from the PEF map were drawn on the PEF map as ancient ruins: Ainouka, Esfaieh, Djatoun, Tell Dahauk; however, we could not find any evidence on the PEF map for the other five missing built-up areas: Kalat Toufanieh, Moukbeya, El Keroum, Kerm es Saheb, and El Mennarah. Some of the missing "built-up areas" were mentioned in the memoirs of "The Survey of Western Palestine" (Conder et al. 1881), e.g., "Kh. Jathun" (named Djatoun on the LG map) – "heaps of stones and modern ruins" (176) and "El Makbiyeh" (named Moukbeya on the LG map) – "A kind of suburb of Nazareth, in a valley near a good spring; said to have had, in 1859, a population of 60 souls" (274) (Conder et al. 1881). Thus, not all spatial information observed by the PEF surveyors, as was written in their memoirs, was included on their maps. While the PEF surveyors used different symbols to distinguish between inhabited built-up areas and ruins, on the LG map the same symbol was used. Disregard or lack of attention to the difference between types of "built-up areas" on the maps may have led to user errors. This point highlights the importance of examining different historical maps of the same period, thus strengthening our understanding of the maps under consideration. Assuming that if a built-up area was shown on one of the two maps, it indeed existed throughout the 1870s, then the LG map succeeded in depicting 99% of all inhabited built-up areas, whereas the PEF map succeeded in depicting 92% of all inhabited built-areas.

Differences found between the two maps may also be the result of human errors, changes in the landscape due to human and natural factors and different cartographic criteria regarding what should be added or omitted from the map. Human errors in maps could be deliberate or accidental. Maps do not necessarily mirror reality and are a powerful tool to illustrate reality as the surveyor is interested in showing (Harley 1989). However, some errors (such as measurement errors) could be accidental and could occur during each of the different stages of mapping, from drawing the map, to scanning and geo-referencing it, and finally to its digitization (Leyk, Boesch, and Weibel 2005). Errors occur most often when dealing with poorly defined objects, which is often the case with natural vegetation features (Brown 1998, Fisher 1999). First, there is the problem of different perceptions that cause ambiguity; for example, each field of research (botany, ecology, biology) classifies nature by a set of different parameters, many of which are subjective; some classify nature by similarities in appearance and features; others by ecological functions and yet others by their genetic similarity (Laurin 2010). Second, after deciding upon a classification, natural features such as vegetated areas may not have clearly defined borders. The surveyor or the person who digitizes the map has to decide where to mark the border between vegetation classes. As these poorly defined features are vague, the interpretation of these features is partly subjective; thus, significant differences may be found between two maps (Tucci and Giordano 2011). We have examined in detail two land-cover classes: built-up areas (well defined) and water bodies (somewhat less defined). By examining the completeness of information of these two features, we demonstrated some of the reasons leading to differences between the two maps.

### *Accuracy of the DEM*

As mentioned in the section "Analyzing the effects of the geo-referencing method of spatial uncertainty," the geo-referencing method employed had no significant effect on our estimations of map accuracy. The error values of the height differences were normally distributed (Figure 7), as found in other studies examining the accuracy of DEMs (Bolstad and Stowe 1994). The magnitude of the height differences (i.e., errors in height) was mainly below 50 meters, which roughly corresponds to the findings of Collier (1972), who reported altitude errors of up to ±100 foot in the steeper slopes on nineteenth-century topographic maps of Scotland. Several of these errors may be related to the manual digitization of the contours; however, image processing methods for extracting linear features, such as contours from topographic maps, may also lead to errors in the extracted features (Gamba and Mecocci 1999; Khotanzad and Zink 2003; Samet and Hancer 2012; Miao et al. 2013). Additional errors in the LG DEM may be related to the interpolation method that we used and the TIN model (Robinson 1994), as well as to source accuracy errors associated with the process of surveying the LG map itself (Levin 2006). All remarkable features of the ground noted by the French surveyors were leveled, and they determined the altitudes of more than 500 points with reference to sea level (Hutchinson 1873). When comparing the mountain peaks found on the LG map to present-day Israeli 1:50,000 maps, we can find the following height differences: the elevation of Mt. Shar-Shalom (616 meters) was marked on the LG map as only 589 meters (a difference of 27 meters); the elevation of Mt. Halutz (729 meters) was marked on the LG map as only 710 meters (a difference of 19 meters), and the elevation of Mt. Zefad (834 meters) was marked on the LG map as 818 meters (a difference of 16 meters). The order of these elevation errors is similar to those reported by Levin (2006) for topographic features on the PEF map (averaging 14 meters for triangulation stations and 19 meters for other topographic point features). The results demonstrated that with an increase in elevation, there is a greater risk of more significant errors in measuring heights and slopes (Bolstad and Stowe 1994). Indeed, many of the measurement errors occur in restricted areas, such as areas of cliffs or tall and dense vegetation (James et al. 2012). Using a budget error calculation (Figure 8), we estimate that most of the vertical errors of the LG map were within a reasonable range.

### *Analyzing historical maps*

For many years historical maps were seen as unreliable and thus of little use (Harley 1968; Koeman 1968; Turnbull 1996). Nonetheless, historical maps are valuable as they contain important information about the past, and it is therefore necessary to examine them and take them into consideration. Moreover, in many countries historical maps and explorers' travelogues are the only documents available that depict past landscape (Collier 2002). In this study, we used two historical maps covering the same area and the same period. When using two historical maps, uncertainties may emerge and result in new questions. Comparing historical maps enables us to verify past land-cover patterns, and to quantify the degree of certainty we have in reconstructing past landscape. Knowing that the overall agreement between the PEF and LG maps was more than 59% and that extensive land-cover classes were also in close agreement increased our confidence that the general lines of the landscape and the cover classes as depicted in the maps are correct. In our study, we found differences in the number of built-up areas between the two maps. These differences were partially resolved by referring to written sources accompanying the PEF maps, i.e., the three volumes of memoirs (Conder et al. 1881) as well as a travelogue written by one of the main surveyors (Conder 1878). When several historical maps are used to reconstruct past landscape (as was done by Levin, Elron, and Gasith 2009 for wetlands along the coastal plain of Israel or by Lukas 2014 for shoreline changes in Java, Indonesia), additional methods can be used to quantify map completeness and to extrapolate land-cover features beyond what is shown on the maps.

## Conclusions

This article has demonstrated the benefits and the problems that may arise when using two independent historical maps, covering the same area and from the same period, to analyze land cover. Historical maps hold valuable information about the past and in many countries, they may be the only documents available for reconstructing past landscape. However, historical maps contain uncertainties that the interpreter or the user of the map must be aware of. This article has also demonstrated that the type of geo-referencing applied to a historical map and the specific set of control points used for geo-referencing a historical map may not affect the assessment of the accuracy of that map. The availability of several maps created independently for a certain area at the same period is a prerequisite for analyzing map completeness. While map scale clearly affects the amount of content and details that can be shown on a map (Levin, Kark, and Galilee 2010), in this study, it seems that scale differences between the two maps did not greatly affect differences in the portrayal of land-cover classes. Analyzing the accuracy and completeness of a historical map is important, as it enables us to ascertain to what degree such historical documents can be relied upon for reconstructing past landscapes. As tribunals are willing to acknowledge the evidentiary value of map evidence more than ever before (Lee 2005), it is increasingly important to quantify the degree to which the content and location shown on historical maps can be relied upon. As shown in this study, these challenges of quantifying errors in historical maps can be met using GIS tools. This article has shown that although analyzing and examining several historical maps is time consuming and could raise new questions, ultimately this approach strengthens our confidence in reconstructing past landscapes from historical maps.

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## Disclosure statement

No potential conflict of interest was reported by the authors.

## Note

1. Variations between the numbers of built-up areas and water bodies given here and those reported in Table 3, are due to the fact that in several cases features such as built-up areas or one marsh land are composed of several polygons. In addition, here we only included inhabited built-up areas, whereas in Table 3 ruins shown on the LG map are also included.

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**Appendix**

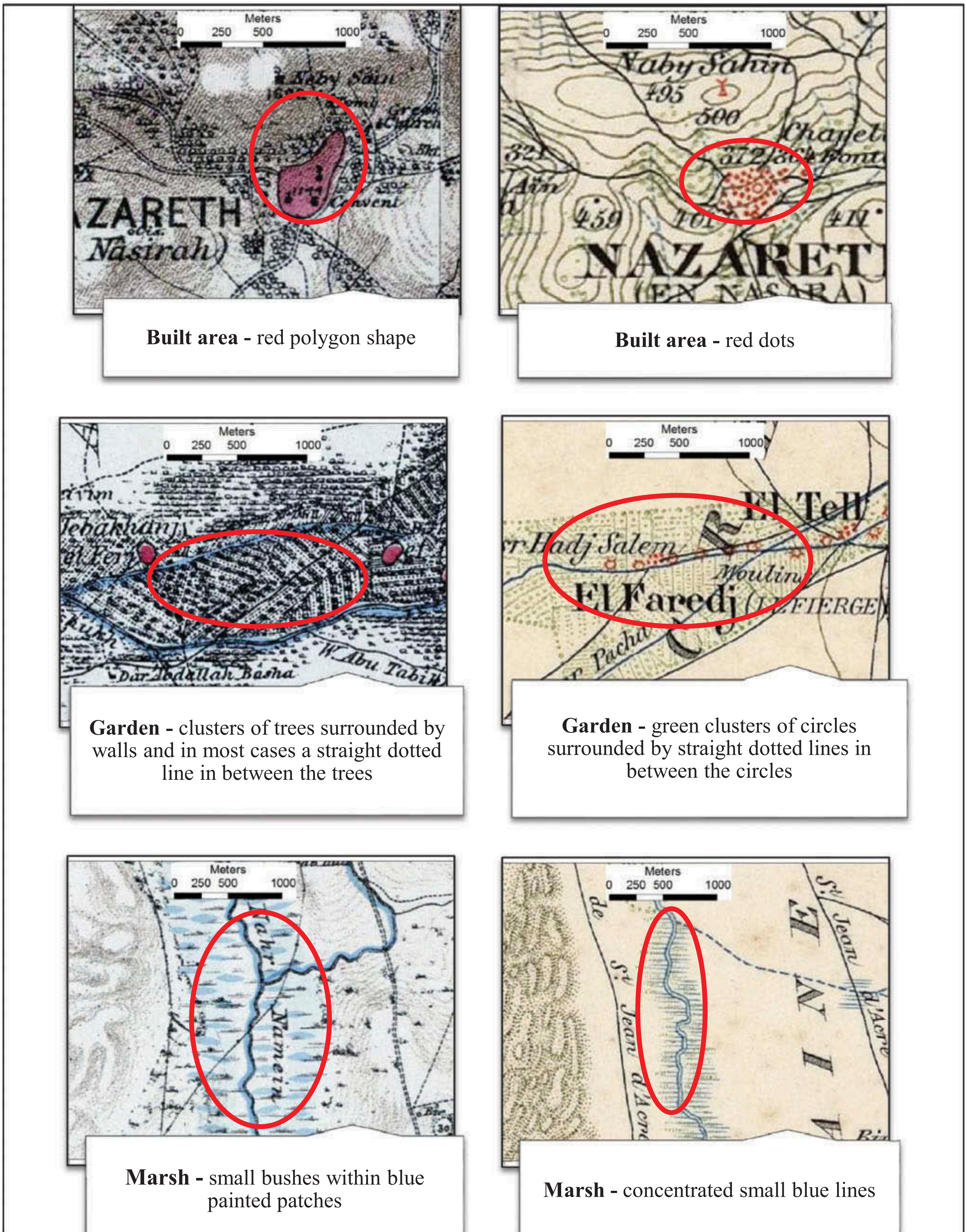


Figure A1. The nine land-cover classes as well as the symbol of ruins as shown on the Palestine Exploration Fund map (left column) and Levés en Galilée map (right column).

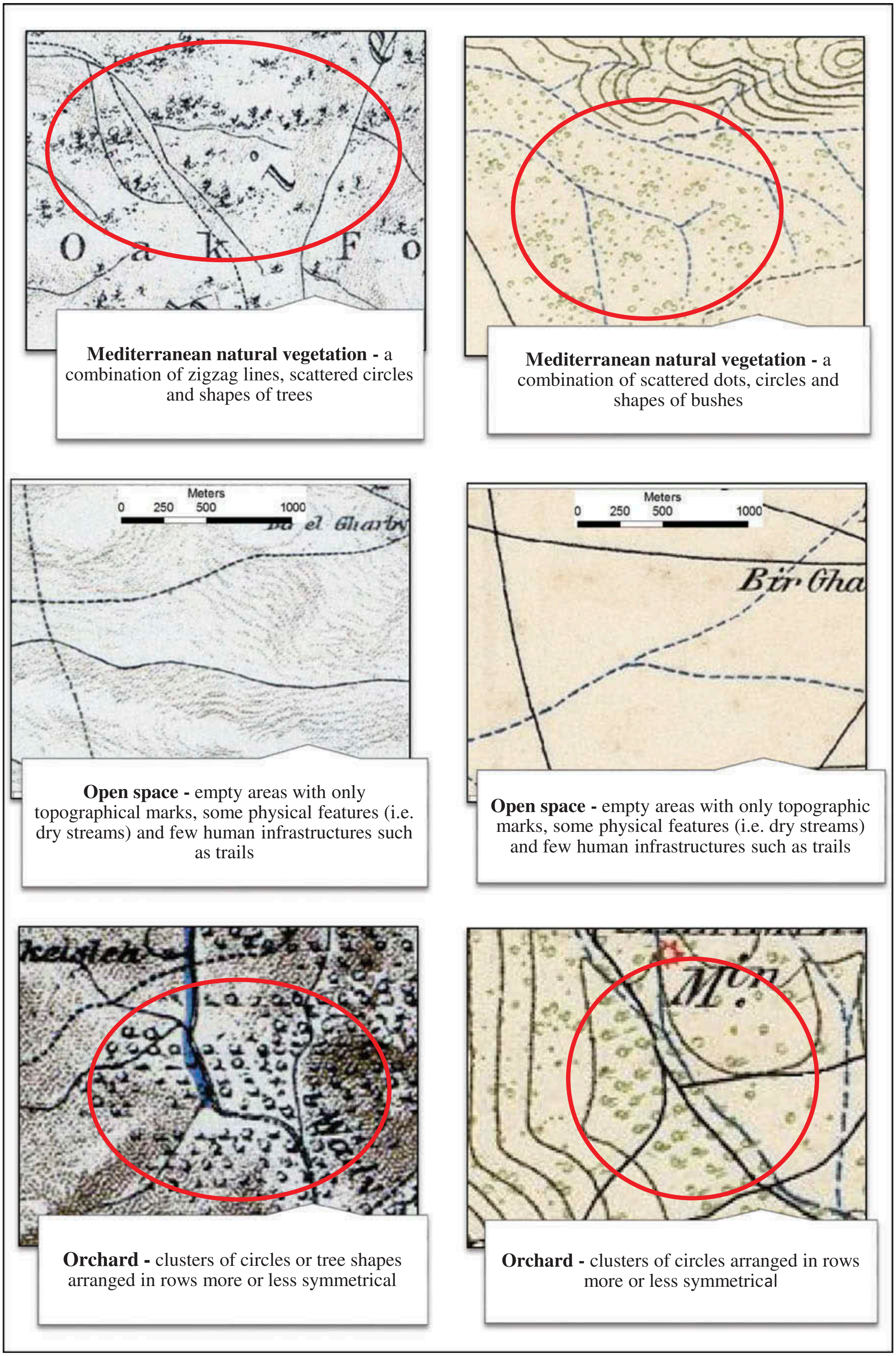


Figure A1. (Continued).

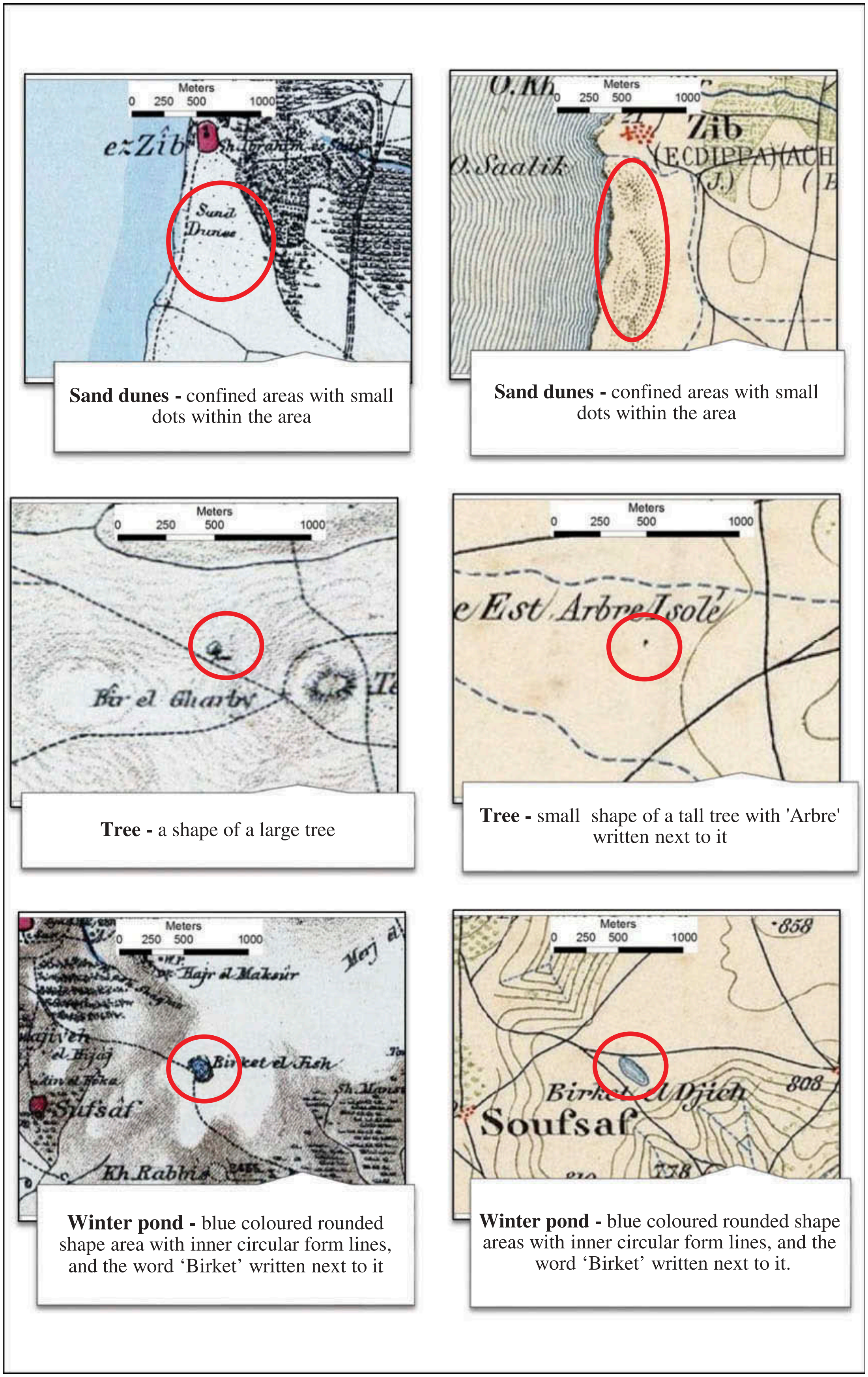


Figure A1. (Continued).

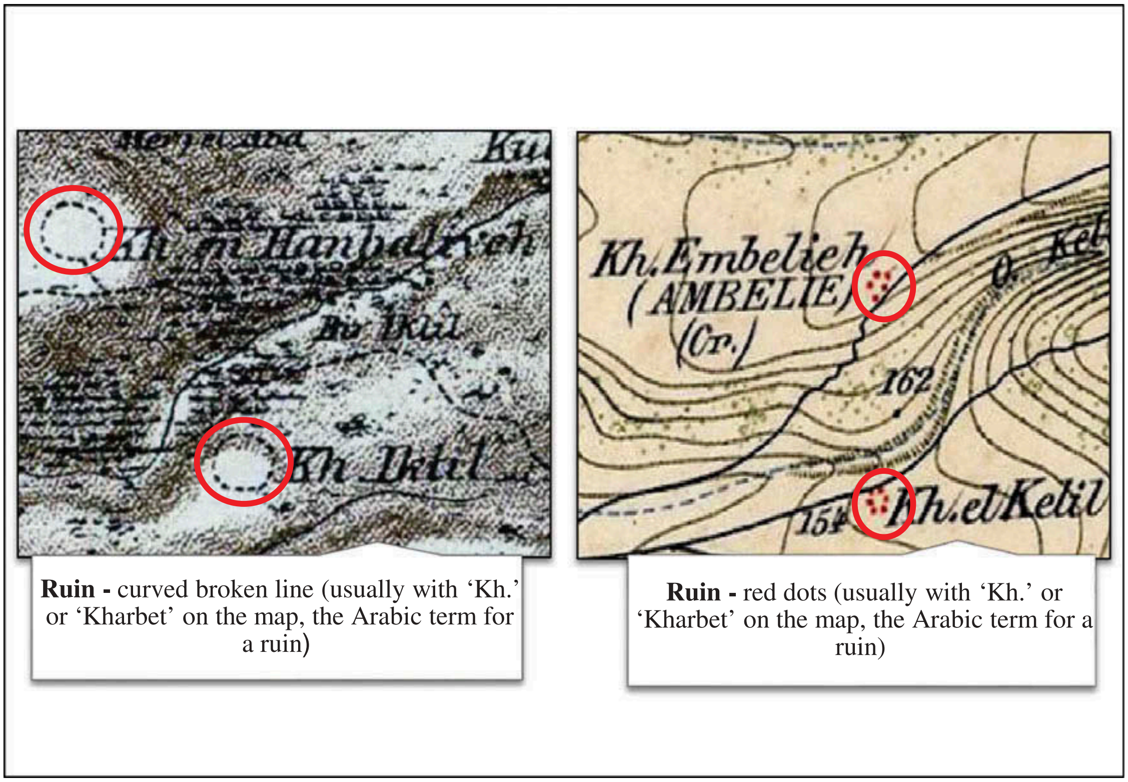


Figure A1. (Continued).

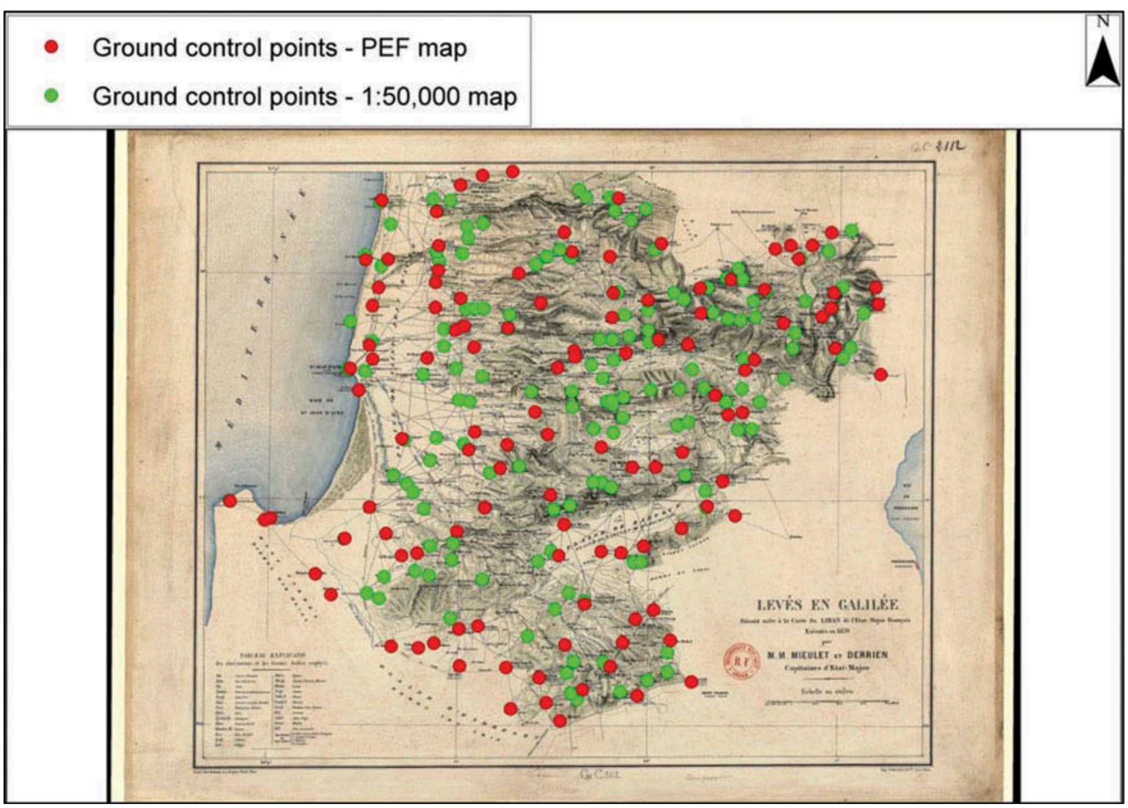


Figure A2. Figure representing the ground control points used for geo-referencing the Levés en Galilée map (shown in the background) to the 1:50,000 topographical maps (using 145 points shown in green) and to the Palestine Exploration Fund map (using 115 points in red).

Table A1. Discrepancies in “built-up areas” between the Levés en Galilée map and the Palestine Exploration Fund map.

| Name on the Levés en Galilée map | Built area found on Levés en Galilée? | Built area found on the PEF? | Name on the PEF map | How does the “built –area” appear on the missing map? | Literary references to those built-up areas (Conder et al. 1881) | Literary references to those built-up areas (Guerin 1868) |
|---|---|---|---|---|---|---|
| Naby Sibel Hann | No | Yes | Neby Sebelay | Name and a triangulation symbol | Village with 100 inhabitants | No mention |
| N/A | No | Yes | German Colony | Open space area | The German Colony is referred to as part of the city of Haifa | A few houses |
| Yanouha | Partially | Yes | Yanuh | One built-up area unlike two built-up areas as on the PEF map | Village with 150 inhabitants | Village |
| Ainouka | Yes | No | Anmukah | Ruin | Is an ancient site, no inhabitants | Small village, a few inhabitants |
| Esfaieh | Yes | No | Kh. Esh Shefeiyeh | Ruin | Traces of ancient ruins, no inhabitants | Small village with a few shepherds |
| Djatoun | Yes | No | Kh. Jathun | Ruin | Modern ruins, no inhabitants | Ruins |
| Tell Dahauk | Yes | No | Kh. Dauk | Ruin | Ruins, no inhabitants | Ruins |
| El Mennarah | Yes | No | N/A | Does not appear | No mention | Abandoned village |
| Kalat Toufanieh | Yes | No | Kulat et Tufauyeh | Name and triangulation symbol | Ruins, no inhabitants | Ruins |
| Kerm es Saheb | Yes | No | N/A | Area of orchards | No mention | No mention |
| Moukbeya | Yes | No | El Makbiyeh | Area of orchards | Once was inhabited but no longer | Small village with 20 houses |
| El Keroum | Yes | No | N/A | Empty space | No mention | No mention |

Table A2. Discrepancies in “water bodies” (including both “winter ponds” and “marsh lands”) between the Levés en Galilée map and the Palestine Exploration Fund map.

| Name on the Palestine Exploration Fund map | Name on the Levés en Galilée map | Water body found on Levés en Galilée? | Water body found on the Palestine Exploration Fund map? | Size of the water body in ha | Which land-cover type is shown instead of the missing water body on the other map? |
|---|---|---|---|---|---|
| Hamed – North of Beit Jenn | N/A | No | Yes | 0.5 | Open space |
| Birket – South east of Beit Djenn | N/A | No | Yes | 0.8 | Open space |
| Yerka | N/A | No | Yes | 0.6 | Orchards |
| Yanuh | N/A | No | Yes | 0.3 | Open space |
| South west of Fassutah | Fasoutha | No | Yes | 0.5 | Open space |
| East of Azz ed Din | Naby Saleh | No | Yes | 57 | Open space |
| North west of Tel es Subat | N/A | No | Yes | 119 | Open space |
| Sahel el Buttauf | Plaine de Battout | No | Yes | 813 | Open space |
| Ein Kana | Ein | Yes | No | 0.6 | On the Levés en Galilée map appears as two “winter ponds.” On the Palestine Exploration Fund map appears only as a name, “Ein” |
| N/A | South of Beit Djenn | Yes | No | 0.7 | Vineyards |
| Sahel Arrabea | Kh. El Merdjem -North east of Saknin | Yes | No | 3.8 | Open space |
| Fassutah | North east of Fasoutha | Yes | No | 0.3 | Open space |