A BETTER-DEVELOPED SOIL PROFILE DURING BIBLICAL TIMES IN THE WESTERN GALILEE. 
15N EVIDENCE IN 14C - DATED GROUNDWATER

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Abstract: Despite almost a hundred years of reforestation efforts, the recharge area of the Judea Group aquifer in the hills of the western Galilee still shows the signs of the severe soil erosion that transpired in previous centuries. At present the soil profile is thin and basement rock is often exposed. Historical and Biblical sources suggest that the hills in the past were more forested. Therefore, the δ15N values of dissolved nitrate were measured in radiocarbon-dated groundwater to see if evidence for past soil conditions could be deduced. Nitrate mineralization processes in soils lead to enrichment in 15N of the residual nitrate, which being dissolved by rain enters into the groundwater without further isotopic fractionation. Previous studies have shown that there is a trend of increasing δ15N in a soil profile from plant, to litter, to the organic material in the soil. In addition, there is a tendency for higher δ15N values to be observed in those samples that have been taken at greater depth in a soil profile due to progressive mineralization and subsequent nitrification of soil organic material. As long as the dissolved oxygen is not depleted, denitrification will not occur to alter the isotopic composition of the dissolved nitrate. The nitrate concentrations and δ15N values, water chemistry, tritium and radiocarbon activities were measured from the phreatic outcrop recharge region, and onwards into the confined portions of the Judea Group aquifer and its continuation into the juxtaposed Kurdani and Pleistocene aquifers. The radiocarbon activity decreases with flow. Tritium values of above 2 TU are restricted to the recharge region. Using an initial 14C activity of 64 pMC the radiocarbon ages of the water are found to range from recent to 7800 BP. The δ15N values of the dissolved nitrate within the young water recharge area fall in the range of +3.1 to +4.8‰ (Air), having a mean of +3.9‰ (n=5). In older water the nitrate concentration increases slightly, while the δ15N ranges from +4.7 to +7.2‰ (Air), having a mean of +6.4‰ (n=17). The increase in the δ15N values in the older water down-dip is not due to denitrification processes; for, the waters are well oxygenated. These older waters infiltrated at the same point of origin in the phreatic portions of the aquifer (non-contaminated) as the recent water. As the earlier infiltrating water flowed down dip they retained the δ15N values of the environment at that time. The δ15N values present evidence that, compared to the present, the soil and plant cover was better developed in earlier times, including Biblical times.

1. INTRODUCTION

There are two dominant processes that cause changes in the landscape. One is human activity and the other is climate change. Beginning with our forebears who traversed the Middle East about 100,000 years ago and spread into Europe and Asia (Stringer and Mckie, 1997), the Land of Israel has always been a zone in which people have wandered back and forth (Fig. 1). To name a few, we have the Egyptians, the Babylonians and the sons of Israel who went to Egypt and came back (Genesis 47:1; Exodus 15: 16-28). Likewise, in more recent times Napoleon and his forces, similar to other armies in the past, marched up from Egypt and back again across the Land. At other times, the Middle East corridor was accessed also from the sea – in Biblical times, e.g. by the Philistines (Amos, 9:7). In the middle Ages, waves of Crusaders came to the land of Israel, by way of the land as well as by the sea (Benvenisti, 1970). All these coming and going through the Middle East left a mark on the landscape. Trees were cut for firewood and for building. Space was cleared for agriculture. The latest and most intensive assault on the landscape was made by the Ottomans, who, during the First World War, cut the forests of the country.

KEY WORDS: Carbon Isotopes, Nitrogen Isotopes, Soil, Landscape Changes, Climate Changes
at a rate of 10 tons/day, to feed their steam locomotives, which traversed the country from the north down to Beer Sheba (Sheffer, 1987). From the Bible, we know that during the Iron Age, at the time of our Patriarchs, the land was covered with extensive forests; although, the trees might not have been big (King Solomon had to import cedars from Lebanon in order to build the temple (I Kings 5:6)).

Israel is not only a passage way but a transition zone between temperate and desert climate regimes. The transition line between these two regimes has been delineated by Goodfriend (1988) near the town of Beer Sheba (Fig. 2). Clearly a northward shift of the desert would profoundly affect the floral landscape. The possibility that the transition zone has not always been anchored near Beer Sheba must be investigated before it can be excluded as having been a cause of forest degradation to the north in the past.

In this paper we investigate the evidence, and evaluate the causes for change in the landscape using climate proxy data, preserved in the groundwater of an important aquifer water in northern Israel, near Haifa (Fig. 2). The aquifer (Fig. 3) is bounded by the hills of the lower Galilee in the east and by the Coastal Plain, to the west (Mero, 1983). The direction of water flow is from the east, where recharge takes place, westwards. The present-day top soil is very thin and in many places the bed rock is exposed. It had been eroded by rain flushing away the bare soil of the denuded hills under the influence of the steep gradient of the terrain, which enabled the process to be very efficient. In the cross section of the Judea Group aquifer (Fig. 4) it is seen that the recharge in the east is into a matrix of limestones and dolomites. Flowing down dip from the phreatic recharge area, the water becomes confined under an impermeable aquiclude. Further towards the sea there are two small aquifers (Kurdani and Pleistocene) overlain by a thick impermeable clay layer. Faulting has juxtaposed portions of the permeable beds of each aquifer against each other. Therefore, this has enabled water from the Judea Group aquifer to drain into, and recharge in turn, the carbonate Kurdani aquifer, and then the sandy Pleistocene aquifer. A small outcrop of the Kurdani aquifer supplies some water to the Pleistocene aquifer as well. Other than this small recharge, no surface water has entered these aquifers except that which has originated in the hill region where the Judea Group outcrops.

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**Fig. 1.** The Land of Israel has served as a land corridor of the Middle East, through which people have migrated and armies have passed for millennia (Modified from Passover Hagada, Koren Publishers; Jerusalem, 1979).

**Fig. 2.** Present day rainfall distribution map of Israel. There is a steep north south gradient in the precipitation. The desert boundary is located today in the vicinity of Beer Sheva. The study area extends from the hills of western Galilee to Haifa Bay, immediately north of Haifa.

**Fig. 3.** Geological map of the study area showing location of the samples. The outcrop area of the Judea Group carbonate aquifer is restricted to the hills in the east. It is overlain by younger, impermeable strata westwards of the recharge. The Kurdani aquifer, which receives drainage from the Judea Group, has only two small surface exposures. The hydrologically connected Pleistocene aquifer is only encountered in the subsurface. The Pleistocene aquifer is not seen at the surface because it is covered by recent dune aquifer.
δ13C values within the approximate range of –20 and –
precipitated as BaCO3 from 50 liters of water. It was con-
trolled for and its subsequent effect on the topsoil was looked for.

In the water, two isotopic proxies were studied to differ-
entiate between the two possible scenarios outlined above. One proxy is the ratio of the stable isotopes of
carbon. The composition of this isotopic ratio in aquifer
water is a result of the combination of inputs of carbon
from two end members: organic matter on the surface and
the matrix through which recharge water passes into the
aquifer (Mook et al., 1974). The source of organic matter
on the surface are plants that have grown there. In a tem-
perate climate these are predominantly C3 plants, with
δ13C values within the approximate range of –20 and –
32‰ (Clark and Fritz, 1997). When a temperate climate
gives way to desert conditions there is a corresponding
change in the flora. The land cover changes from C3 to
predominantly C4 plants. The latter are characterized by
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As the other end member is a carbonate rock matrix, hav-
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the dissolved bicarbonate in the water will be approxi-
mately half of the average soil gas value. Thus, if the aqui-
er water were to exhibit a marked enrichment in13C, this
would be supportive of a climatic control; whereby, the
erosion would have resulted from a northward excursion
of the desert boundary from its present position.

The second proxy is the nitrogen isotope 15N. The ni-
trogen in water is also derived from organic matter in the
top soil: when it is thick, more time is available for pro-
duction of ammonia and the 15N of nitrates becomes more
enriched. Previous studies have shown a trend of increas-
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higher δ15N values in samples that have been taken at
greater depth in a soil profile, due to progressive miner-
alization and subsequent nitrification of soil organic ma-
terial (Lajtha and Michener, 1994). By contrast, when the
topsoil is thin, the time of ammonia production is short
and the δ15N of the nitrate should be lower. Once in the
aquifer the isotopic signature of the dissolved nitrate will
not change unless either additional nitrate is added along
the water flow path, or if bacterial denitrification (which
occurs only under anaerobic conditions) of the dissolved
nitrate takes place. In the aquifer under consideration
both these effects can be excluded for: (1) no additional
inputs of nitrate, even if such sources were to have exis-
ted, could penetrate through the impermeable confining
aquicludes, and (2) the water of the Judea Group aquifer
is well oxygenated (8-9 mg/l in the recharge region
and 4-7 mg/l in the confined region (Rogojin, 2000)). Thus,
anaerobic conditions never prevailed to allow for the al-
teration of the isotopic signature of the dissolved nitrate
by denitrification processes. Therefore, we feel confident
that the δ15N values of the groundwater at each sampling
site reliably reflect the isotopic signature of the dissolved
nitrate at the time of recharge. To use these proxies in
a historical context, we dated the aquifer water with 14C
and with tritium.

2. METHODS

Water samples were collected from pumping wells that
exploit this multi-aquiferial system, with the purpose of
finding isotopic evidence for the timing and the causes of
changes in the landscape above the recharge area. More
specifically, evidence for the dilution or elimination of flora
and its subsequent effect on the topsoil was looked for.

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a historical context, we dated the aquifer water with 14C
and with tritium.

3. EXPERIMENT

The sampling was carried out in 1994-1996. Samples
for nitrogen analyses were collected in 1 liter plastic
bottles. The analyses were carried out at the Center for
Scientific and Industrial Research in Pretoria, South
Africa, using a SIRA 24 mass-spectrometer. The 615N
values are reported relative to atmospheric air, with a pre-
cision of 0.15‰. Radiocarbon analyses required 50-liter
samples. The tritium and radiocarbon analyses were mea-
sured at the Radiocarbon Dating Laboratory at the
Weizmann Institute of Science in Rehovot, Israel. The
tritium was enriched by electrolysis, converted to ethane
and detected in proportional counters. Tritium concen-
trations are reported in tritium units (1 TU = 1 atom tri-
ut per 1018 atoms of hydrogen). The associated stan-
dard deviation is reported at the 1σ level of confidence.
The precision was better than 0.3 TU. Radiocarbon
measurements were carried out on the CO2 that was
precipitated as BaCO3 from 50 liters of water. It was con-
verted to ethane and 14C was detected in proportional
counters. The results are expressed in percent with respect
to "modern carbon" (pMC), with the associated statisti-
cal counting error at the 1σ level of confidence. The pre-
cision was better than 0.6 pMC. δ13C was measured
using an Atlas MAT 250 mass spectrometer with a preci-
sion of 0.1‰.
4. RESULTS

Table 1 summarizes the data used in our interpretation. No NO\textsubscript{3} was detected. The $\delta^{15}N$ values of the dissolved nitrate within the recharge area fall in the narrow range of +3.1 to +4.2‰. They gradually change to higher values along the flow path, reaching +6 to +7‰. The nitrate values range from 12 to as high as 38 mg/L nitrate but there is no consistent change in the nitrate concentrations with flow. The tritium values vary with geographical position. There are measurable amounts of tritium in the phreatic recharge, and none in the confined sections of the aquifer. The radiocarbon concentration varies from 64-70 pMC in the phreatic region where tritium is encountered, to 46 pMC in the well furthest the down-dip (the Afeq-B well). The $\delta^{13}C$ values vary from -14.0 to -18.6‰ (PDB). In the Kurdani aquifer the $\delta^{13}C$ values vary from -12.3 to -15.2‰ (PDB), while the radiocarbon activity is in the range of 50-55 pMC. The nitrate values are similar to those most frequently encountered in the Judea Group water being in the range of approximately 12 to 23 mg/L, with a corresponding range in $\delta^{15}N$ values +5.6 to +7.0‰. The radiocarbon activity of the water of the Pleistocene aquifer is much lower, 24.8 and 32.6 pMC; otherwise, it has a similar range nitrogen of isotopic values.

To convert the measured radiocarbon activity of the water to an absolute age it is necessary to determine its initial activity. According to the model of Ingerson and Pearson (1964), the range of the initial activity of (pre-thermonuclear) radiocarbon in the water is 64-66 pMC. Kroitoru et al. (1989), using mass-balance considerations, calculated the initial radiocarbon activity for recharge water in the Judea Group aquifer to be 62±3 pMC. We therefore use 64 pMC to calculate the ages of the water in the aquifer (Table 1). Clearly, values above 64 pMC have a component of thermonuclear radiocarbon and are regarded modern. The oldest water in the main aquifer is about 2800 years old. This defines the flow rate of this aquifer to 5 m/yr, which is comparable with the rate of flow of other carbonate aquifers in Israel (e.g. Kronfeld et al., 1992). The waters in the Kurdani and Pleistocene aquifers are significantly older, the oldest being about 7800 BP. Yet, they exhibit $\delta^{13}C$ and $\delta^{15}N$ values that are similar to those from the confined portions of the main aquifer. The hydraulic gradient near the coast is very small, and this can explain the big difference in water ages over small distance.

Table 1. Radiometric age data and nitrogen isotopic data in the multi-aquiferal system of the Western Galilee

<table>
<thead>
<tr>
<th>Sample Code #</th>
<th>Wells</th>
<th>Aquifer*</th>
<th>Tritium [TU]</th>
<th>$\delta^{13}C$ [% PDB]</th>
<th>$\delta^{14}C$ [pMC]</th>
<th>Age [BP]</th>
<th>NO\textsubscript{3} [mg/l]</th>
<th>$\delta^{15}N$ [% Air]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Young samples from recharge region</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>41</td>
<td>Meged Kramim-1</td>
<td>J.G.</td>
<td>2.9±0.2</td>
<td>-15.1</td>
<td>64.0±0.6</td>
<td>Recent</td>
<td>14.6</td>
<td>3.7</td>
</tr>
<tr>
<td>42</td>
<td>Meged Kramim-2</td>
<td>J.G.</td>
<td>2.6±0.2</td>
<td>-14.6</td>
<td>70.1±0.4</td>
<td>Recent</td>
<td>15.5</td>
<td>4.0</td>
</tr>
<tr>
<td>43</td>
<td>Meged Kramim-3</td>
<td>J.G.</td>
<td>1.7±0.2</td>
<td>-14.9</td>
<td>66.1±0.5</td>
<td>Recent</td>
<td>12.4</td>
<td>3.1</td>
</tr>
<tr>
<td>44</td>
<td>Hazon-3</td>
<td>J.G.</td>
<td>5.6±0.2</td>
<td>-15.4</td>
<td>83.1±0.4</td>
<td>Recent</td>
<td>22.6</td>
<td>4.8</td>
</tr>
<tr>
<td>45</td>
<td>Hazon-4</td>
<td>J.G.</td>
<td>1.5±0.2</td>
<td>-15.5</td>
<td>76.4±0.4</td>
<td>Recent</td>
<td>20.4</td>
<td>4.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Samples from confined section of the aquifer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>38</td>
<td>Miar</td>
<td>J.G.</td>
<td>0.5±0.3</td>
<td>-15.7</td>
<td>59.8±1.0</td>
<td>561±140</td>
<td>19.0</td>
<td>6.5</td>
</tr>
<tr>
<td>20</td>
<td>Akko-2</td>
<td>J.G.</td>
<td>1.9±0.2</td>
<td>-18.6</td>
<td>56.9±0.5</td>
<td>972±73</td>
<td>23.5</td>
<td>6.8</td>
</tr>
<tr>
<td>40</td>
<td>Lokhamey HaGetto-Dror</td>
<td>K</td>
<td>2.0±0.2</td>
<td>-15.2</td>
<td>55.3±0.4</td>
<td>1208±60</td>
<td>22.6</td>
<td>6.9</td>
</tr>
<tr>
<td>39#</td>
<td>Ahhud</td>
<td>J.G.</td>
<td>0±0.2</td>
<td>-12.9</td>
<td>55.1±0.6</td>
<td>1238±90</td>
<td>12.4</td>
<td>4.7</td>
</tr>
<tr>
<td>6</td>
<td>Afeq-C</td>
<td>K</td>
<td>0±0.2</td>
<td>-14.3</td>
<td>51.6±0.3</td>
<td>1780±49</td>
<td>12.0</td>
<td>5.6</td>
</tr>
<tr>
<td>16</td>
<td>Damun-5</td>
<td>J.G.</td>
<td>0.4±0.2</td>
<td>-14.0</td>
<td>50.5±0.4</td>
<td>1959±65</td>
<td>19.0</td>
<td>6.8</td>
</tr>
<tr>
<td>9</td>
<td>Kefar Masaryk-K</td>
<td>K</td>
<td>0.4±0.2</td>
<td>-12.3</td>
<td>50.0±0.7</td>
<td>2041±116</td>
<td>23.6</td>
<td>6.9</td>
</tr>
<tr>
<td>18</td>
<td>Akko-4</td>
<td>J.G.</td>
<td>1.1±0.2</td>
<td>-16.7</td>
<td>49.8±0.4</td>
<td>2074±66</td>
<td>14.6</td>
<td>5.1</td>
</tr>
<tr>
<td>13</td>
<td>Damun-3</td>
<td>J.G.</td>
<td>1.1±0.3</td>
<td>-14.5</td>
<td>48.3±0.4</td>
<td>2327±69</td>
<td>38.5</td>
<td>7.0</td>
</tr>
<tr>
<td>7</td>
<td>Afeq-B</td>
<td>J.G.</td>
<td>0±0.2</td>
<td>-14.6</td>
<td>45.8±0.4</td>
<td>2766±73</td>
<td>17.3</td>
<td>6.6</td>
</tr>
<tr>
<td>4</td>
<td>Qiryat Khaim-24</td>
<td>P</td>
<td>0.2±0.2</td>
<td>-14.2</td>
<td>32.6±0.4</td>
<td>5577±102</td>
<td>10.2</td>
<td>6.1</td>
</tr>
<tr>
<td>33</td>
<td>Qiryat Khaim-22</td>
<td>P</td>
<td>0±0.2</td>
<td>-12.7</td>
<td>24.8±0.2</td>
<td>7838±67</td>
<td>11.5</td>
<td>7.2</td>
</tr>
<tr>
<td></td>
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<td></td>
<td>Samples in confined section of the aquifer with measured $\delta^{15}N$ but lacking concomitant radiocarbon ages</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>Birwa-3</td>
<td>J.G.</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
<td>-</td>
<td>13.7</td>
<td>5.9</td>
</tr>
<tr>
<td>19</td>
<td>Akko-3</td>
<td>J.G.</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
<td>-</td>
<td>16.4</td>
<td>7.0</td>
</tr>
<tr>
<td>15</td>
<td>Damun-4</td>
<td>J.G.</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
<td>-</td>
<td>25.7</td>
<td>6.8</td>
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<tr>
<td>14</td>
<td>Damun-1</td>
<td>J.G.</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
<td>-</td>
<td>31.9</td>
<td>6.4</td>
</tr>
<tr>
<td>10</td>
<td>Kefar Masaryk-K</td>
<td>K</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
<td>-</td>
<td>18.6</td>
<td>7.0</td>
</tr>
</tbody>
</table>

J.G. = Judea Group, K = Kurdani, P = Pleistocene,
# = a difference was noted, for this sample, between the nitrate concentration measured before the isotopic analysis and the yield of N that was produced in the laboratory- possibly indicating that the isotopic analysis is suspect.
5. DISCUSSION

The $^{13}$C in the aquifer is quite depleted (Table 1) and this suggests that the organic end-member of carbon in the water, which came from the organic matter of the top-soil, have always been C$_3$ plants. For a contribution from C$_4$ plants we would expect values of $\delta^{13}$C around $-7\%e$ and this is clearly not the case. We can thus conclude that the change in the land cover was not due to the shift of the desert line from Beer Sheba to the Lower Galilee.

Fig. 5 shows the $\delta^{15}$N data for water in the aquifer, as a function of the age of the water, calculated from radiocarbon. The broad picture is a practically stable value of $\delta^{15}$N in the +6 to +7%e range. This is in the range of $\delta^{15}$N found in the literature for soil organic matter (Gormly and Spalding, 1979; Heaton, 1984; Komor and Anderson, 1993). There are 5 additional measurements (Table 1) for the confined portion of the aquifer that also fall within this range; but, as we have no dates for them they are not presented in Fig. 5. Though the aquifer contains one continuous water body, there is a sharp break in the nitrate isotopic compositions that delineates the older from the younger water groups, in which the $\delta^{15}$N of the dissolved nitrate decreases to as low as +3.5%e. This change is taken not as an isotopic evolution process that occurred within the aquifer. No isotopic fractionation can be attributed to bacterial denitrification within the downdip segment of the aquifer to raise the $\delta^{15}$N; for denitrification requires anoxic conditions and the waters are well oxygenated. Indeed, no lowering of the nitrate concentration is noted. Thus, the measured $\delta^{15}$N values have not been altered within the aquifer. Therefore, these values reflect the degree of isotopic fractionation of nitrogen within the soil before the nitrate entered the aquifer. Thus it appears that the groundwater preserves and records the changes in the nitrogen isotopes of the dissolved nitrate, which in turn is related to – and thus records – the thickness of the soil and the extent of the overlying plant cover of the last few centuries, when the region was ruled by the Ottoman empire. This process, that led to erosion, could have begun with uncontrolled grazing by goats, in conjunction with the cutting of trees to avoid taxation and culminated with the massive destruction of forests for use in the Ottoman steam locomotives, at the beginning of the 20th century. Whatever, the precise sequence of events, by the end of the Ottoman rule, the landscape of the Galilee was largely denuded of trees and soil. This necessitated large-scale reforestation projects that are still ongoing. The nitrogen isotopic data supports the biblical description.

There are 3 data points in Fig. 5 with $\delta^{15}$N that fall below the average for the older water. One of them (No. 6) (Fig. 4) is also an outlier in the age gradient of the aquifer. However, this well is very close to the small outcrop of the Kurdani aquifer, which has a very thin soil cover (Fig. 3). Therefore the water in this well could be a mixture of the main aquifer water with young water, characterized by higher $^{14}$C activity combined with lower $\delta^{15}$N. If we take $\delta^{15}$N=+3.5%e for the young water and $\delta^{15}$N=+7.0%e for the main aquifer, we find that this sample from the Kurdani aquifer is composed of 40% young water and 60% water from the main aquifer. Assuming that the $^{14}$C content of the young water is 64 pMC, we find the $^{14}$C content of the water from the main aquifer to be 43.3 pMC with a corresponding age of 3130 BP. This age is quite consistent with the gradient of ages along the direction of flow in the main aquifer.

The other two points are well behaved hydrologically and therefore they could be either an artifact or perturbation of the grand trend, or they could represent actual historical events. As historical events, they seem to suggest reversible changes in the land cover: thinner topsoil, or less organic matter in the top soil. The historical timing of these data points are Hellenistic, and some 300 years after the Arab conquest of the land, just before the Crusaders. Until we have some more data, the interpretation must remain speculative. It is clear, however, that a highly eroded soil profile produces much less isotopic fractionation of $^{15}$N than a well developed soil profile, like the one that covered the land when lions roamed the forests of Judea (I Kings 13:24).

6. CONCLUSION

Our analysis shows that of the two potential culprits responsible for the changes in the land cover of northern Israel only one is to blame, namely, the changes brought about by human hands. There is no evidence that the desert line migrated this far north from its present position during the last 8000 years. We think that it is of interest to note that an aquifer can be an archive for the history of environmental processes.
REFERENCES


