THE MICROBIOLOGY OF THE DEAD SEA: PAST, PRESENT, AND FUTURE

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THE INSTITUTE OF LIFE SCIENCES

THE HEBREW UNIVERSITY OF JERUSALEM, ISRAEL

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15 October 2009


AT THE GREAT WALL
八達嶺長城
1994年7月17日

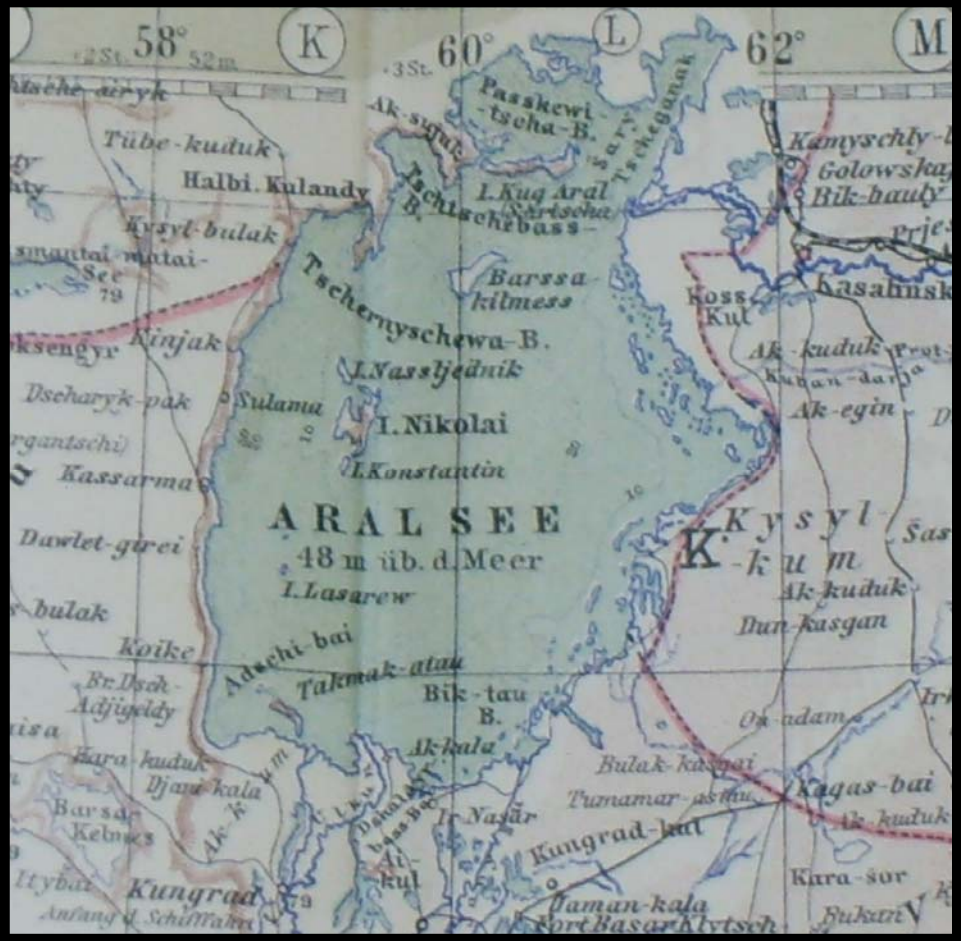
The International Society for Salt Lake Research

Since 1979, an informal international association of salt lake researchers have sponsored a series of triennial conferences to foster scientific exchange and further our understanding of saline lakes

In 1999, at the 7th International Conference on Salt Lake Research held in Death Valley, CA, participants voted to incorporate the International Society for Salt Lake Research (ISSLR)

ISSLR was founded to establish effective liaison between persons interested in any aspect of inland saline waters, to encourage these interests, and to educate the public in the scientific use, management, and conservation of salt lakes

Our web site: http://isslr.org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Golowska
Bik-bauly
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Halbi. Kulandy
I. Kuq Aral
Tschuschebass-B.
Kysyl-bulak
Barssa-kilmess
Tschernyschewa-B.
I. Nassljednik
I. Nikolai
I. Konstantin
ARAL SEE
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Kassarma
Dawlet-girei
Koike
Adschi-bai
Takmak-atau
Bik-tau B.
Ak-kala
Kungrad
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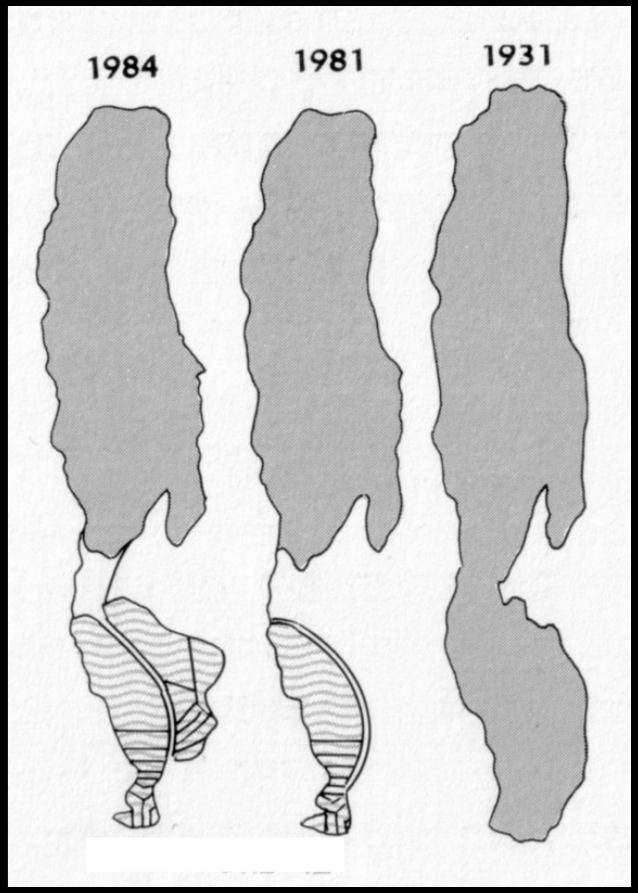
Kara-sor
Kaman-kala
Kagas-bai
Ak-kuduk
Dun-kasgan
Ak-egin
Kossa Kul
K. Kysyl-kum

1939

2002


Dead Sea

1872

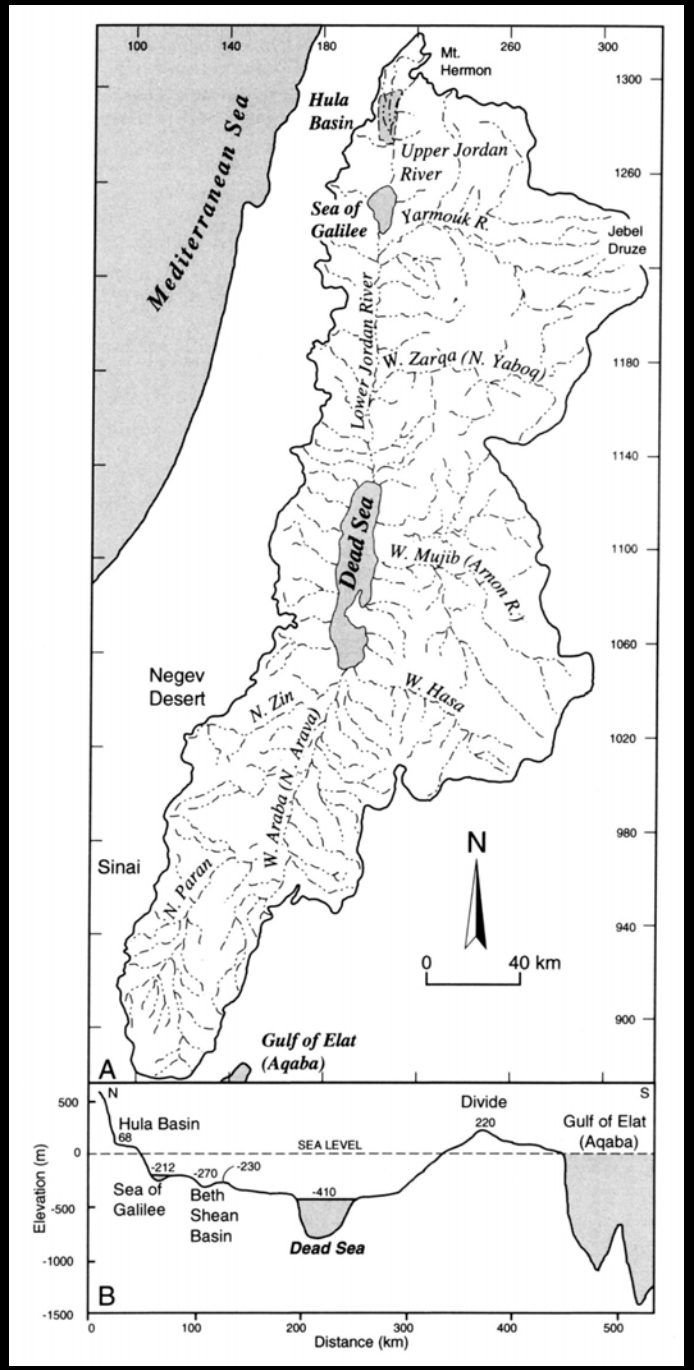


790 km²

1000 km²

1987

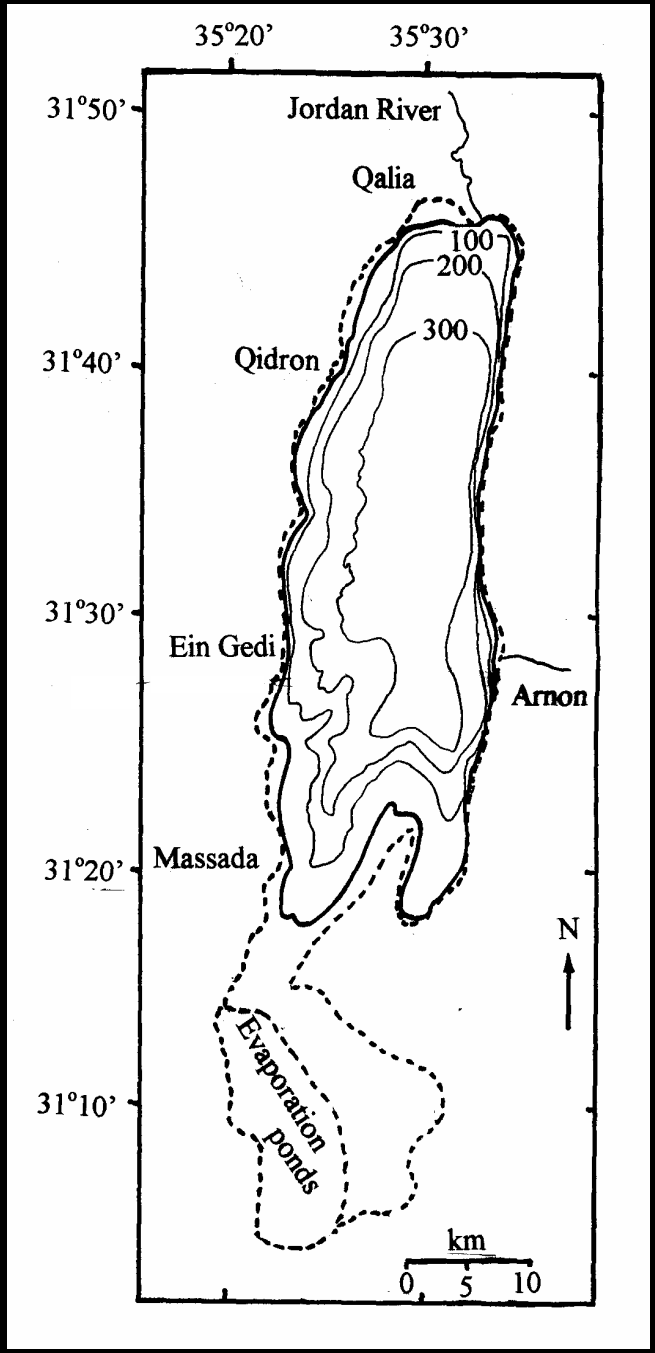
The drainage basin of the Dead Sea



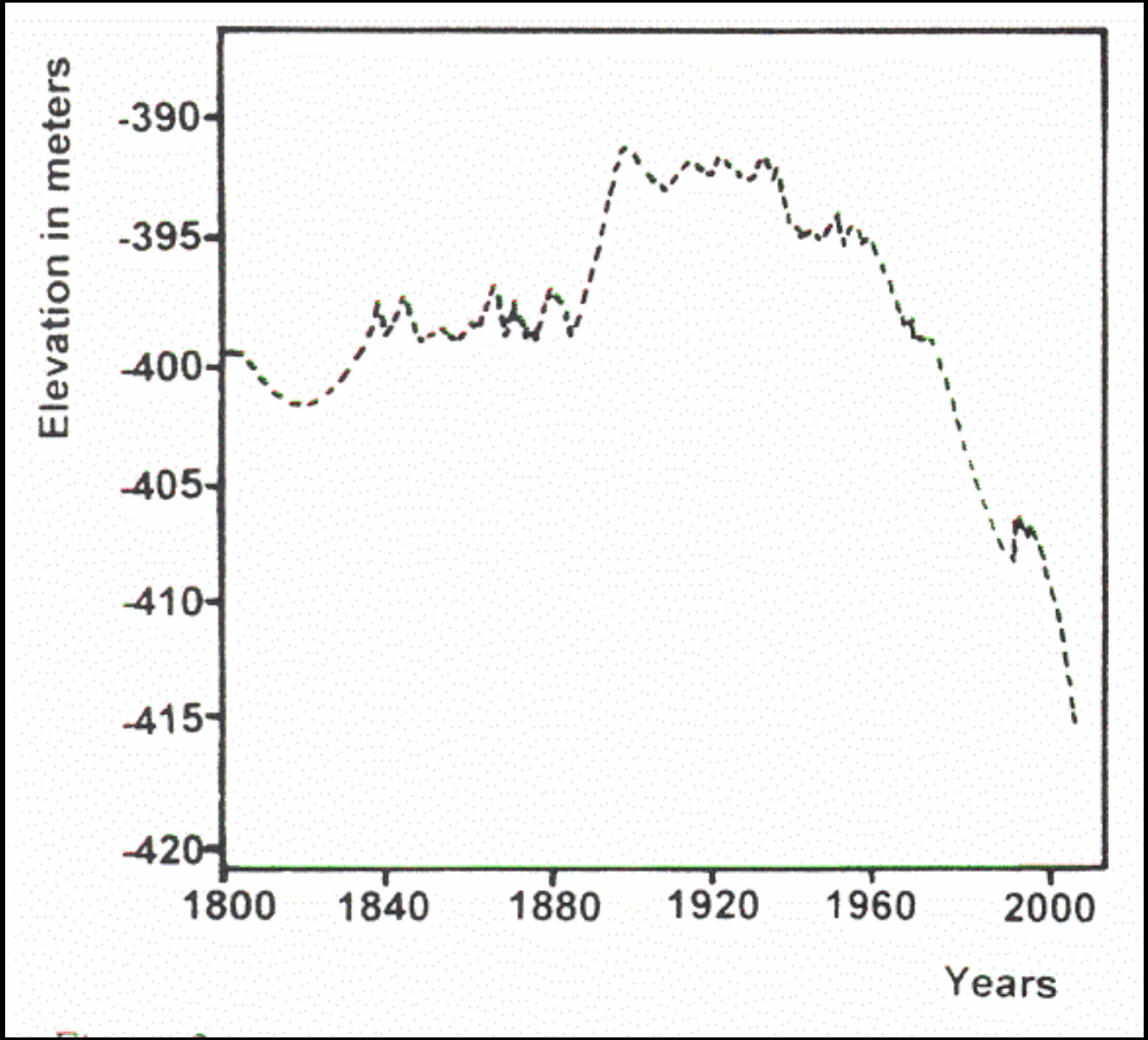
Bathymetric map of the Dead Sea

Flow through the Jordan river in the past:
around 1000 x 10^6 m^3/year

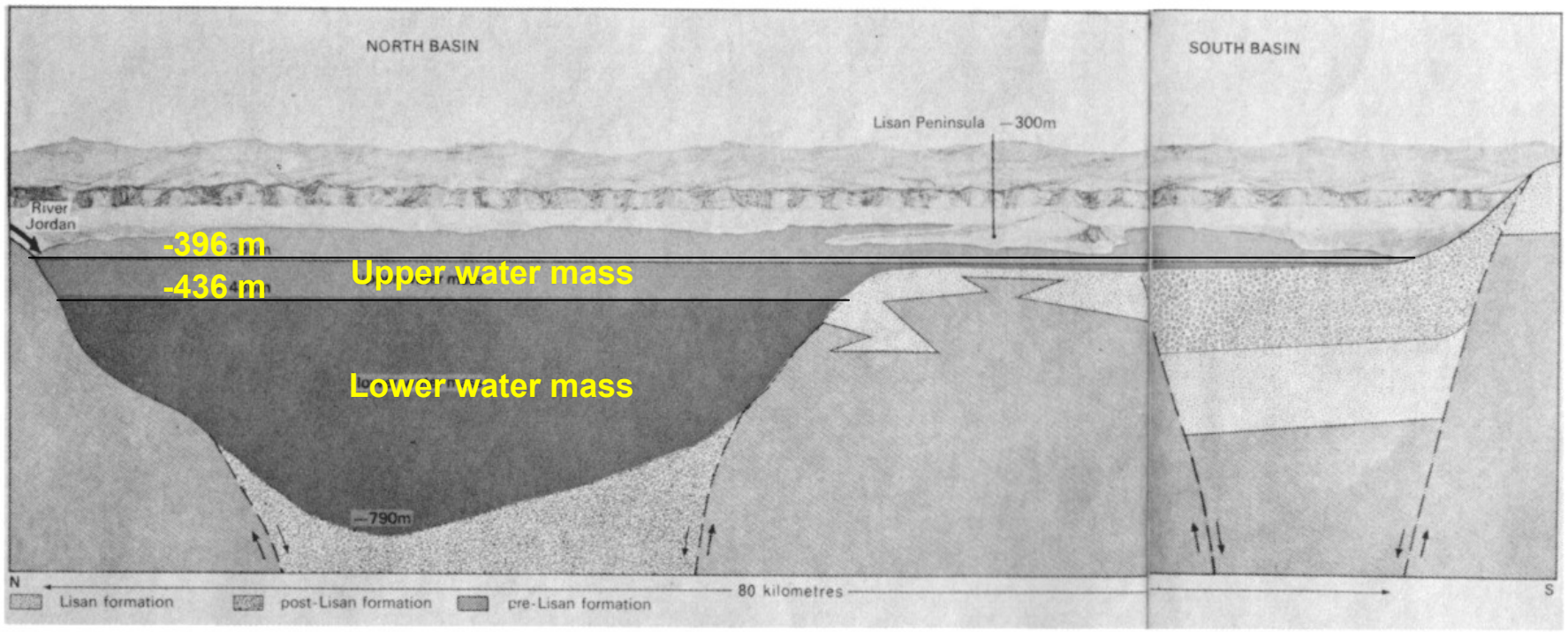
Presently:
less than 50 x 10^6 m^3/year



Dead Sea water levels – 1800-2002



The Dead Sea – May 2008



SCHEMATIC SECTION of the Dead Sea from north to south, with exaggerated vertical scale, reveals the great depth of the north basin compared with the south basin which is nowhere deeper than six metres. Below a depth of about 40 metres the water of the north basin is 'fossil' water; it is saltier and denser than the water above and has different salt concentrations. Section also shows the faulting which has produced the two basins

Stratification ceased to exist in February 1979

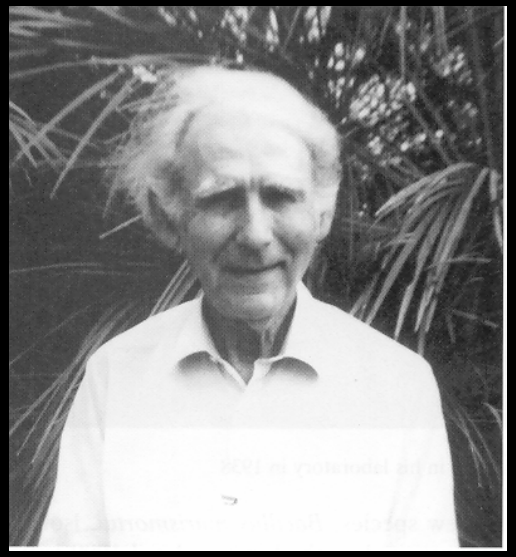
The ionic composition of the Dead Sea

	1977 (average)	1996 (average)	2007 (average)
Ion			
Na^+	1.73	1.59	1.54
K^+	0.18	0.20	0.21
Mg^{2+}	1.81	1.89	1.98
Ca^{2+}	0.43	0.44	0.47
Cl^-	6.34	6.34	6.48
Br^-	0.07	0.07	0.08
SO_4^{2-}	0.005	0.005	0.004

Total dissolved salts: about 340 g/l

pH: about 6.0

“Life in the Dead Sea” – Benjamin Elazari-Volcani (Wilkansky), 1936



Life in the Dead Sea

THE remarkably high salt tolerance of unicellular organisms, which have been found in a saline lake of salt concentration so high as 19-26 per cent sodium chloride by Ruben Tschik, T. Hof, Baas-Becking and others, caused us to doubt the accuracy of the reputation of lifelessness, which tradition imputes to the

Dead Sea. Accordingly, samples of Dead Sea water were taken under sterile conditions at a distance of 3-4 km. from the mouth of the Jordan at various sea depths up to 7 metres. The total salt concentration of the water samples was 28-29 per cent. Bacterial organisms could be grown in 1 per cent peptone sample water media at temperatures of 21°-23° C. and 30° C. from all the samples taken.

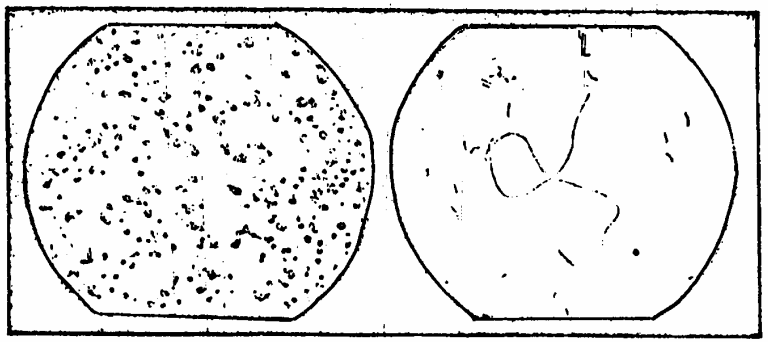


FIG. 1. Dead Sea micro-organisms. × 550.

In addition, microscopic examination of a hanging drop of the water revealed the presence of a living phytoflagellate 13μ long, which we believe is either a *Chlamydomonas* or a *Dunaliella*. Three micro-organisms have so far been distinguished: a yeast-like, Gram-negative orange pigment producer 1·6 × 1·6μ (Fig. 1*a*), a Gram negative small rod-like organism 1–4·8μ × 0·8μ, and a Gram positive long filamentous organism (Fig. 1*b*) 3·3–9·9μ to 170μ × 0·8μ. The investigations are being continued.

We take this opportunity of expressing our thanks to Mr. M. A. Novomoysky, managing director of the Palestine Potash Co. Ltd., for his most kind assistance.

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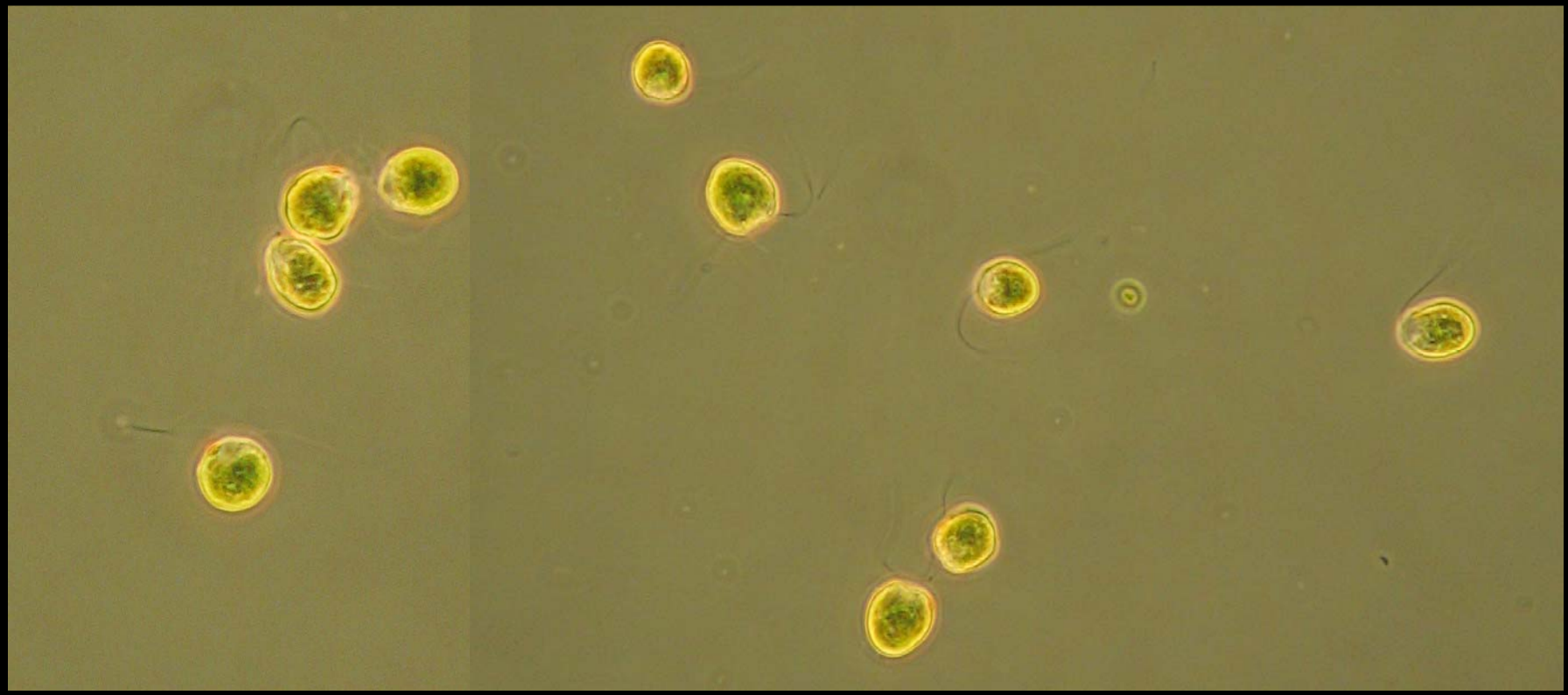
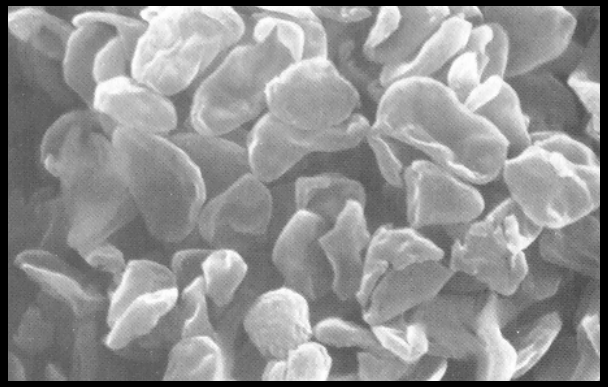
Dunaliella from the Dead Sea

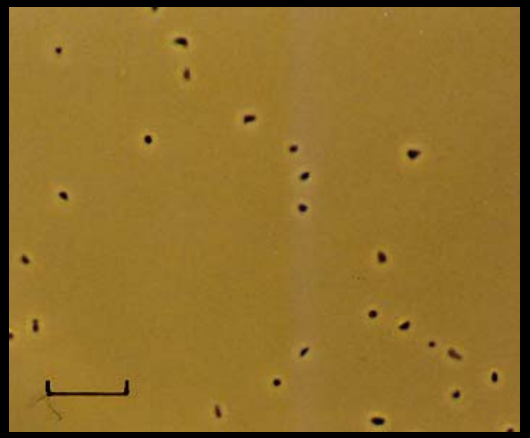


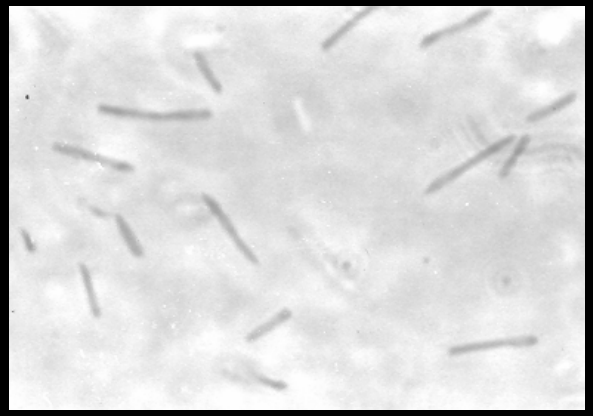
Halophilic Archaea from the Dead Sea



Haloferax volcanii

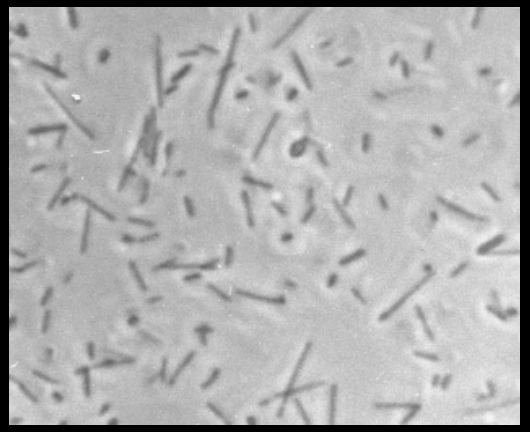
Haloarcula marismortui



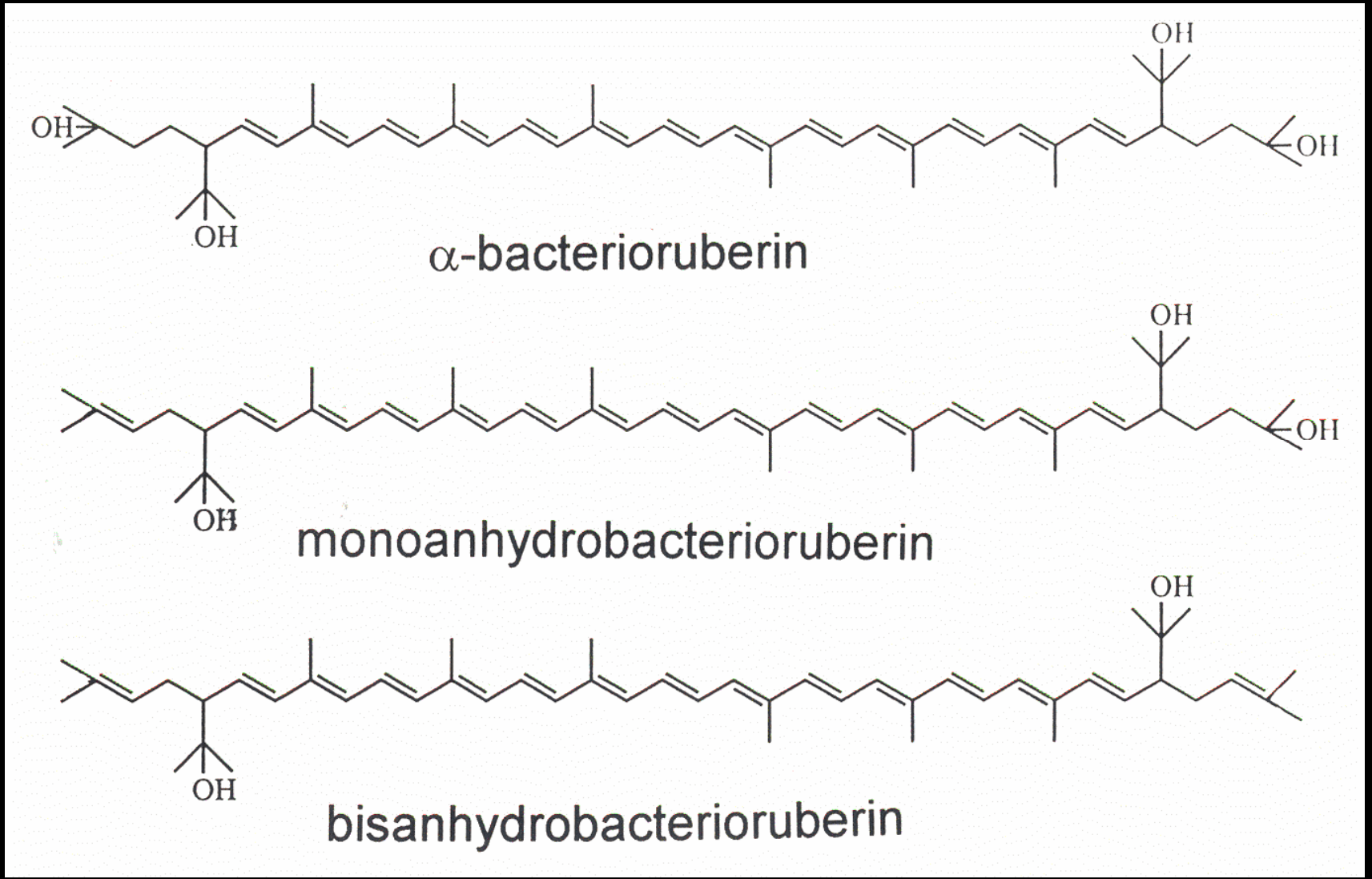


Halorubrum sodomense

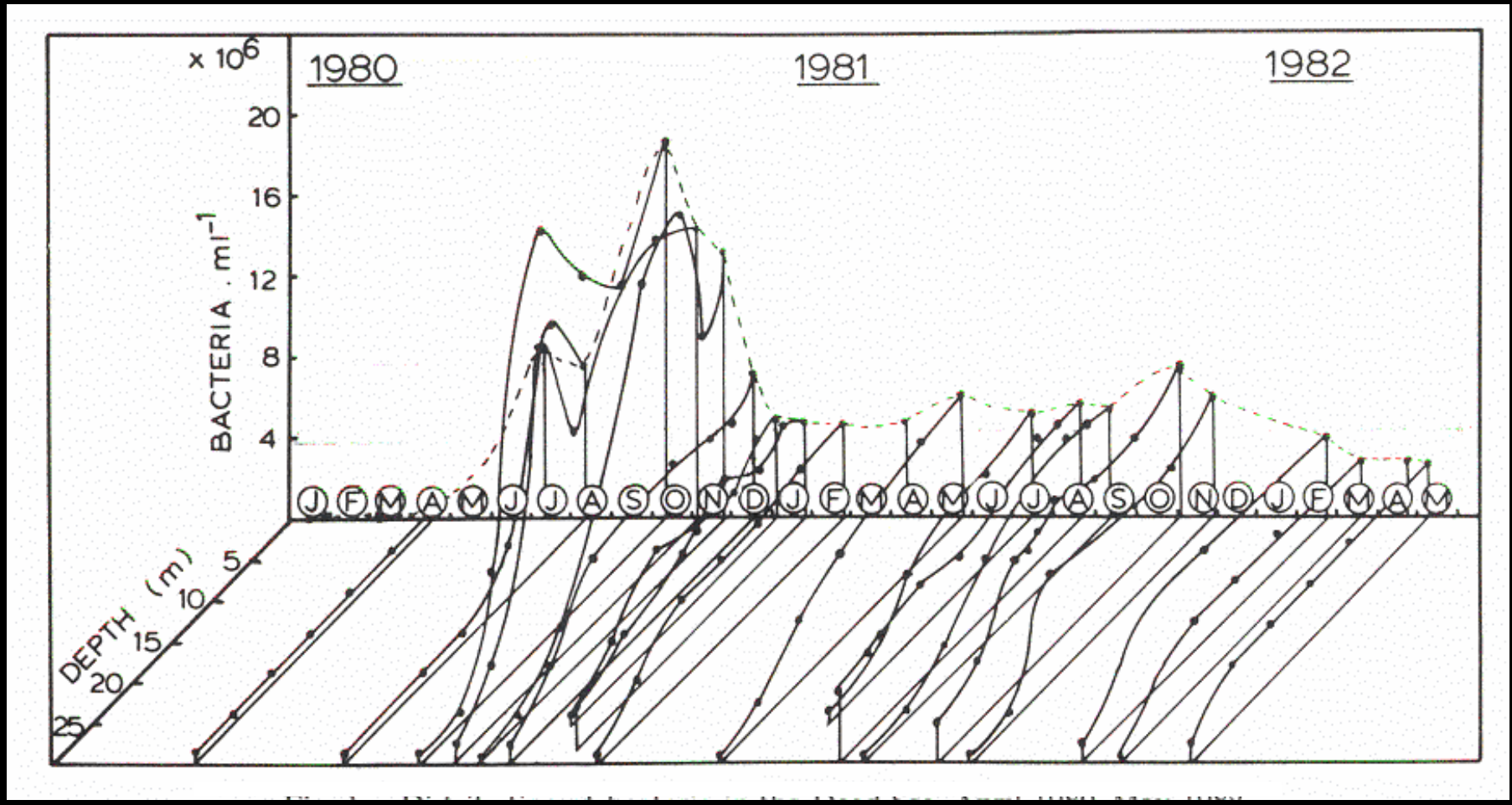
Halobaculum gomorrense



C_{50} carotenoids of halophilic Archaea

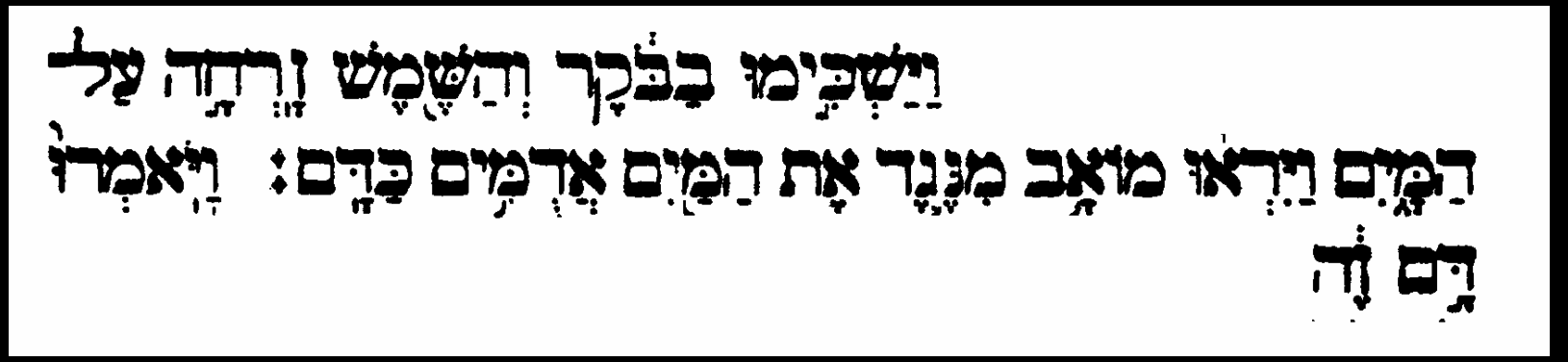


The 1980 archaeal bloom in the Dead Sea



In the summer of 1980 the water was red!

An early record of a “red” Dead Sea?


וַיַּשְׁכִּימוּ בַבֹּקֶר וְהַשֶּׁמֶשׁ זָרְחָה עַל
הַמָּיִם וַיַּרְא מוֹאָב מִנֶּגֶד אֶת הַמַּיִם אֲדֻמִּים כַּדָּם׃ וַיֹּאמְרוּ
דָּם זֶה

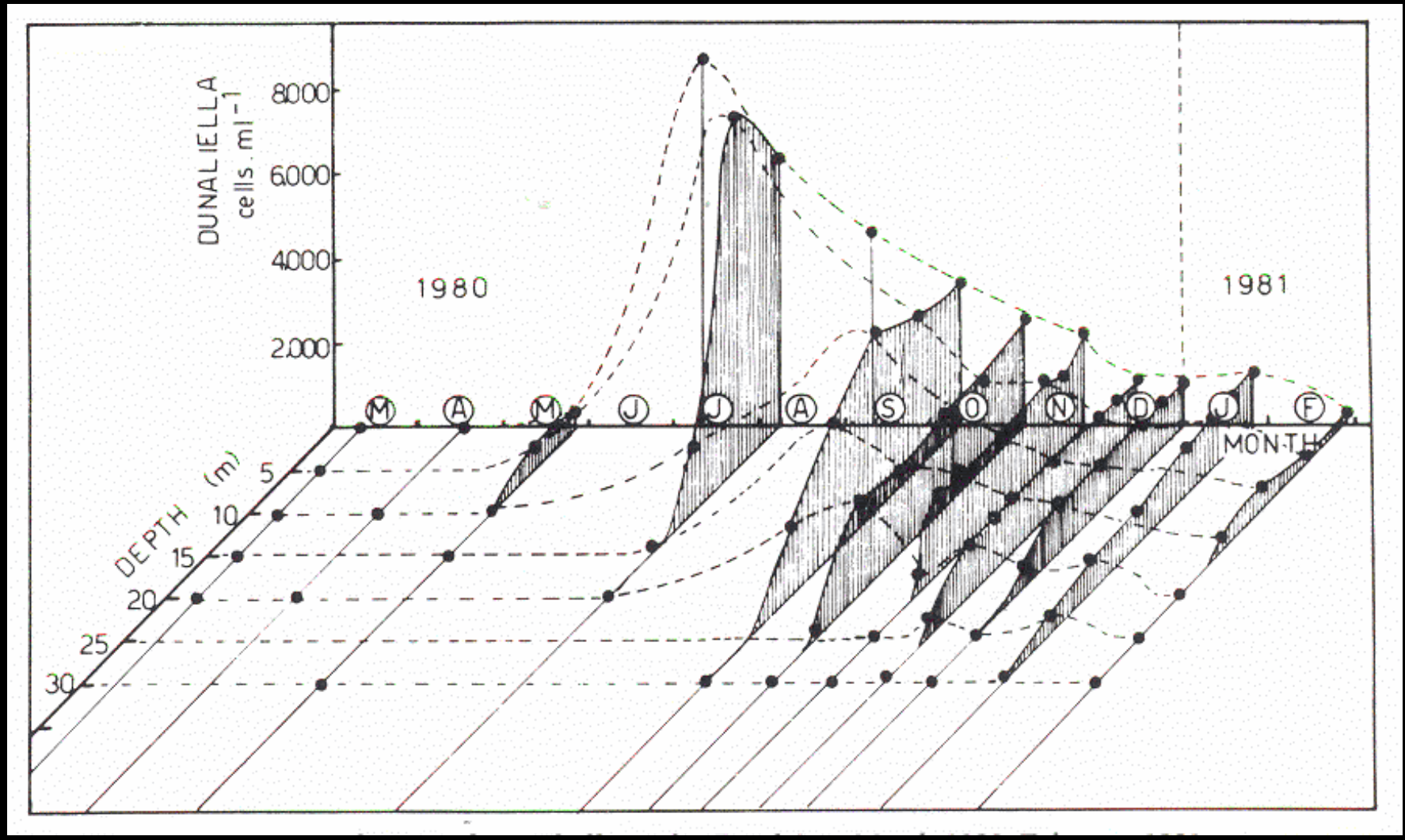
(2 מלכים ב: 22-23)

Поутру встали они рано, и когда солнце воссияло над водою, Моавитянам издали показалась эта вода красною, как кровь. И сказали они: это кровь;

And when they rose early in the morning, and the sun shone upon the water, the Moabites saw the water opposite them as red as blood. And they said: “This is blood …”

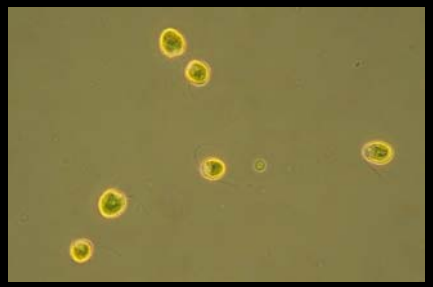
(2 Kings 3: 22-23)

The 1980 *Dunaliella* bloom in the Dead Sea

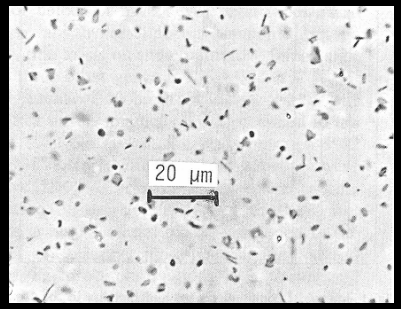


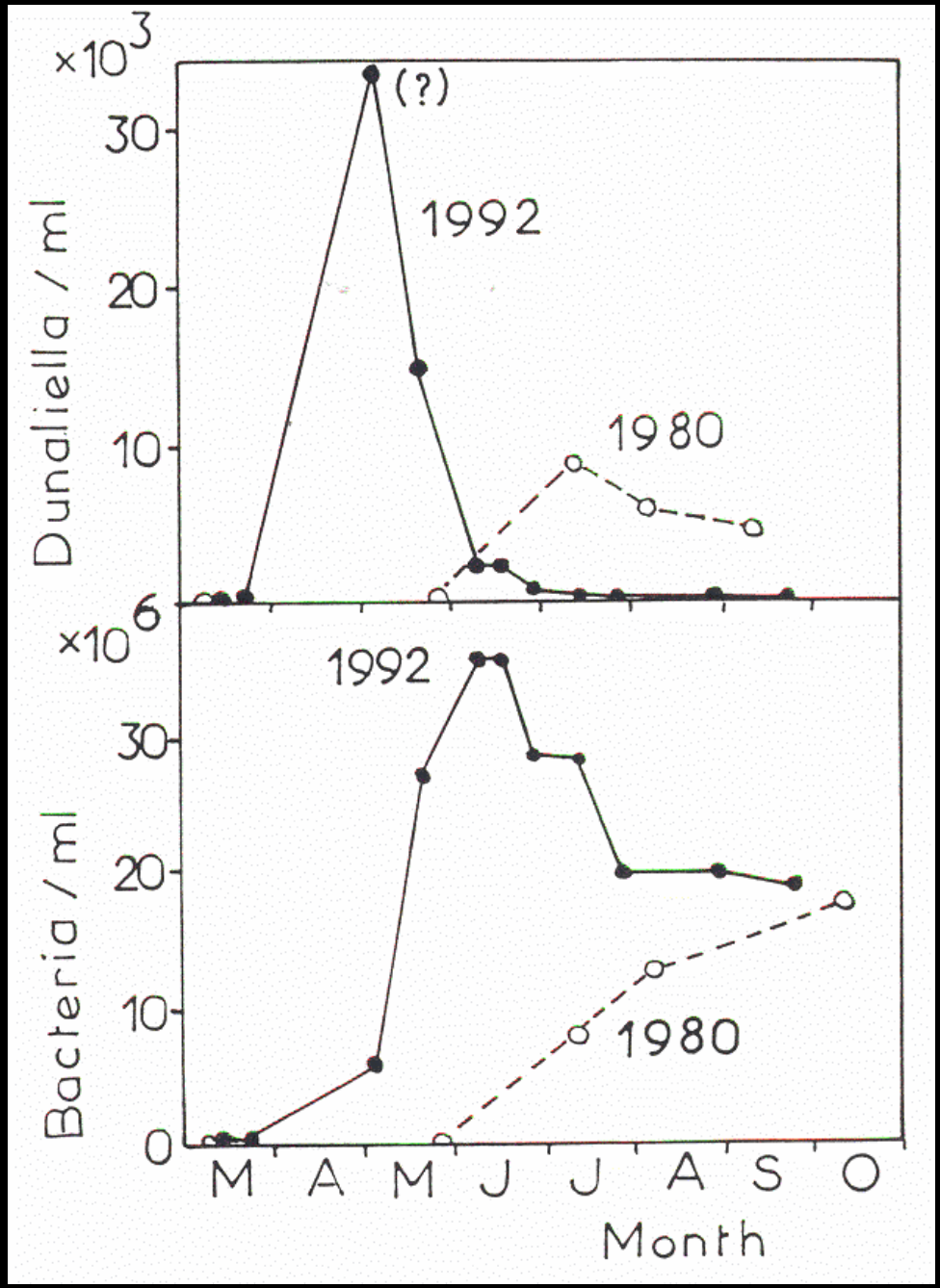
Phosphate is the limiting inorganic nutrient in the Dead Sea

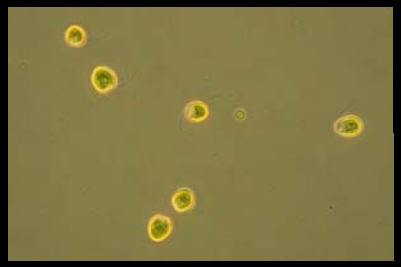
Nitrogen (NH_4^+) is abundantly available in the Dead Sea



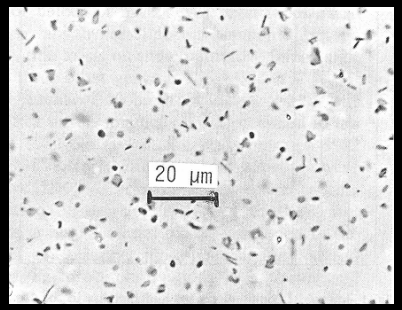
Comparison of the 1980 and 1992 microbial blooms in the Dead Sea

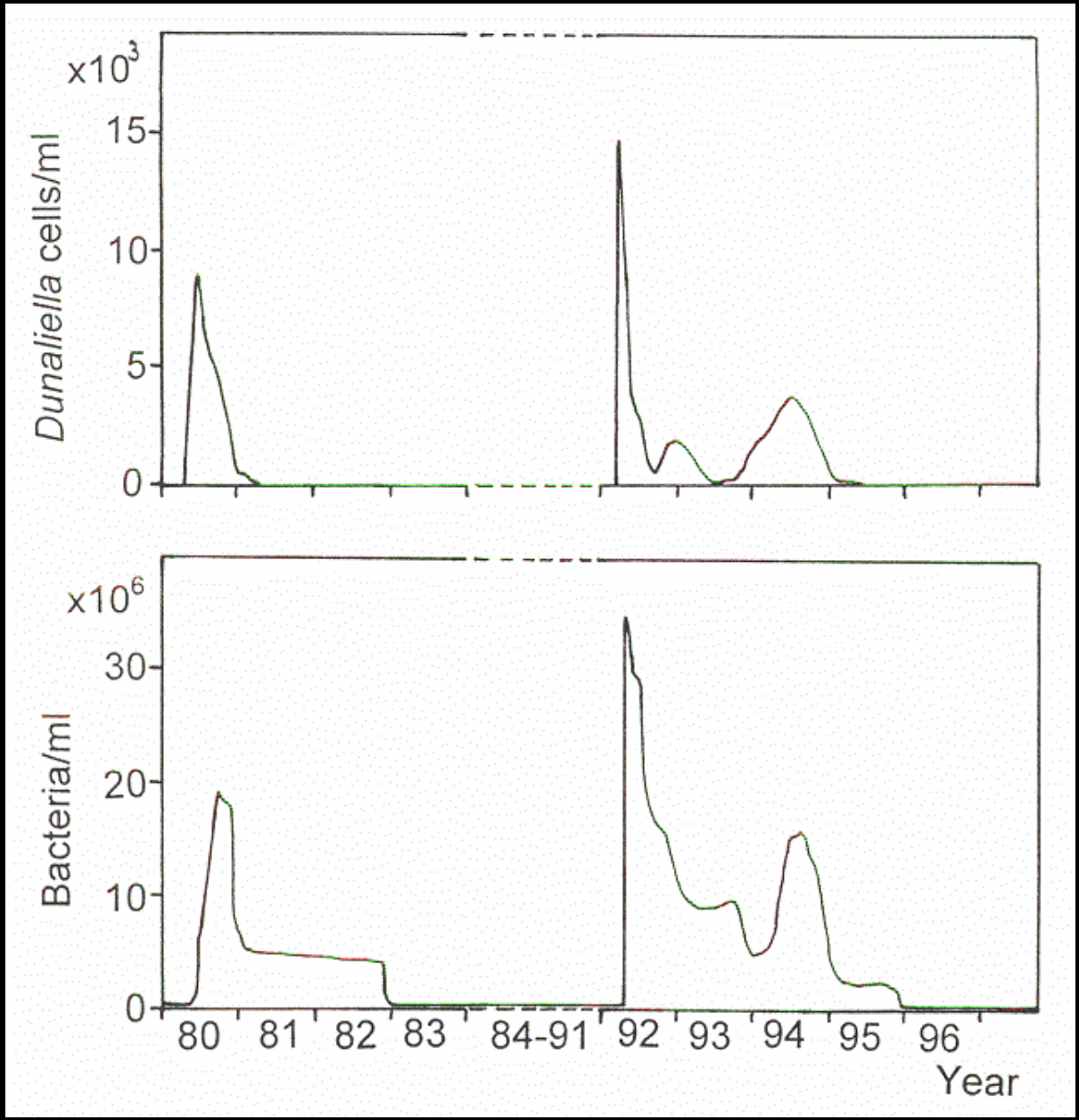






The biology of the Dead Sea – 1980-1997





Metagenomics efforts:

1. **The current (2007) microbial community in the Dead Sea**

2. **Preserved material from the 1992 microbial bloom**

Aharon Oren

Idan Bodaker

Itai Sharon

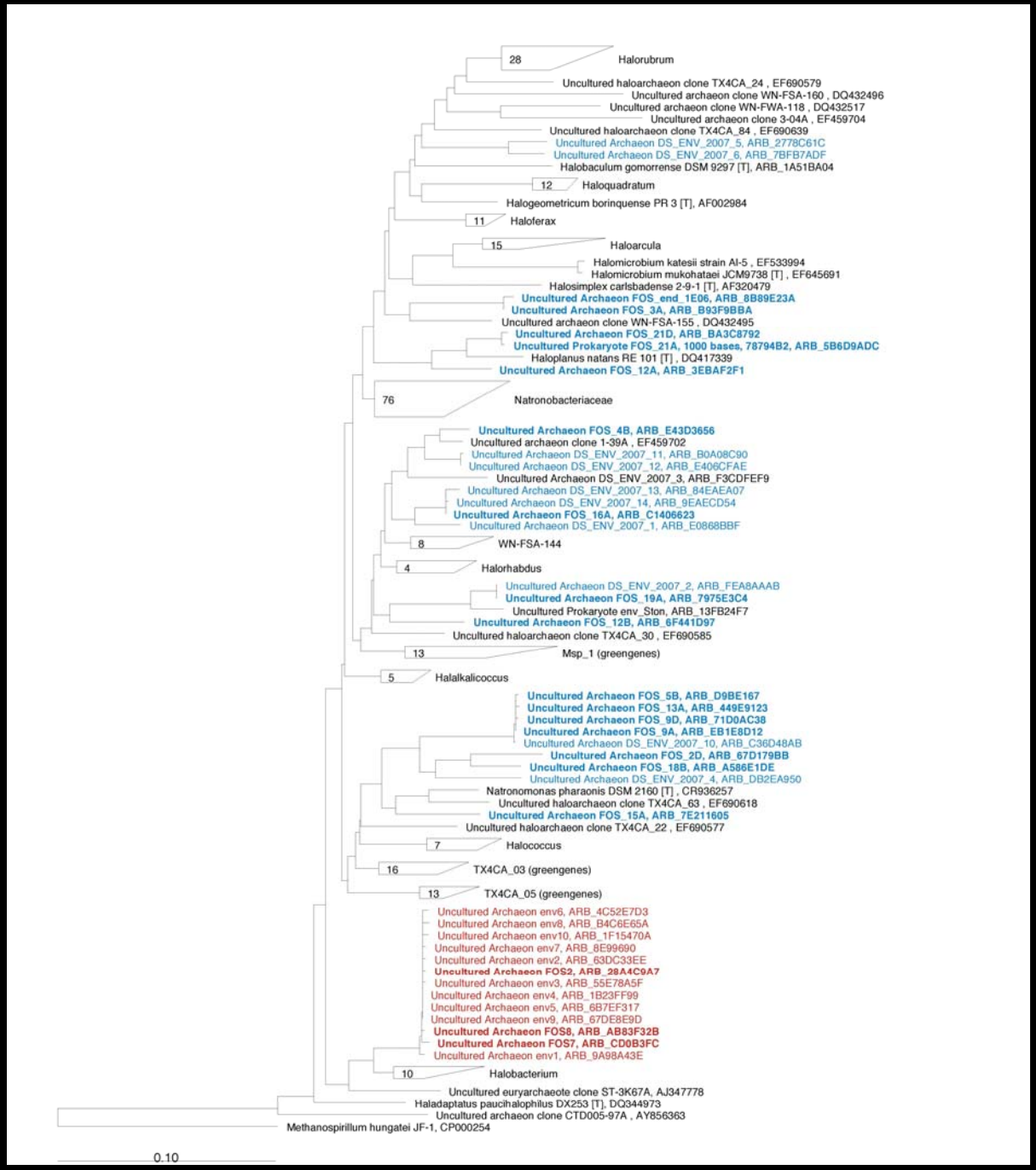
Oded Béjà,

Mira Rosenberg

Moshe Rhodes

Christopher House

The Hebrew University of Jerusalem
Technion – Israel Institute of Technology, Haifa
Penn State University, University Park, PA, USA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Uncultured archaeon clone WN-FWA-118 , DQ432517
Uncultured archaeon clone 3-04A , EF459704
Uncultured haloarchaeon clone TX4CA_84 , EF690639
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Uncultured Archaeon DS_ENV_2007_6, ARB_7BFB7ADF
Halobaculum gomorrense DSM 9297 [T], ARB_1A51BA04
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Haloquadratum
Halogeometricum borinquense PR 3 [T], AF002984
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Haloferax
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Haloarcula
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Uncultured Archaeon DS_ENV_2007_3, ARB_F3CDFEF9
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Uncultured Archaeon FOS_16A, ARB_C1406623
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WN-FSA-144
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Halorhabdus
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Uncultured Prokaryote env_Ston, ARB_13FB24F7
Uncultured Archaeon FOS_12B, ARB_6F441D97
Uncultured haloarchaeon clone TX4CA_30 , EF690585
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Msp_1 (greengenes)
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Halalkalicoccus
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Uncultured haloarchaeon clone TX4CA_22 , EF690577
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Halococcus
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TX4CA_03 (greengenes)
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TX4CA_05 (greengenes)
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Uncultured Archaeon FOS2, ARB_28A4C9A7
Uncultured Archaeon env3, ARB_55E78A5F
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Uncultured Archaeon FOS7, ARB_CD0B3FC
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Haladaptatus paucihalophilus DX253 [T], DQ344973
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Methanospirillum hungatei JF-1, CP000254
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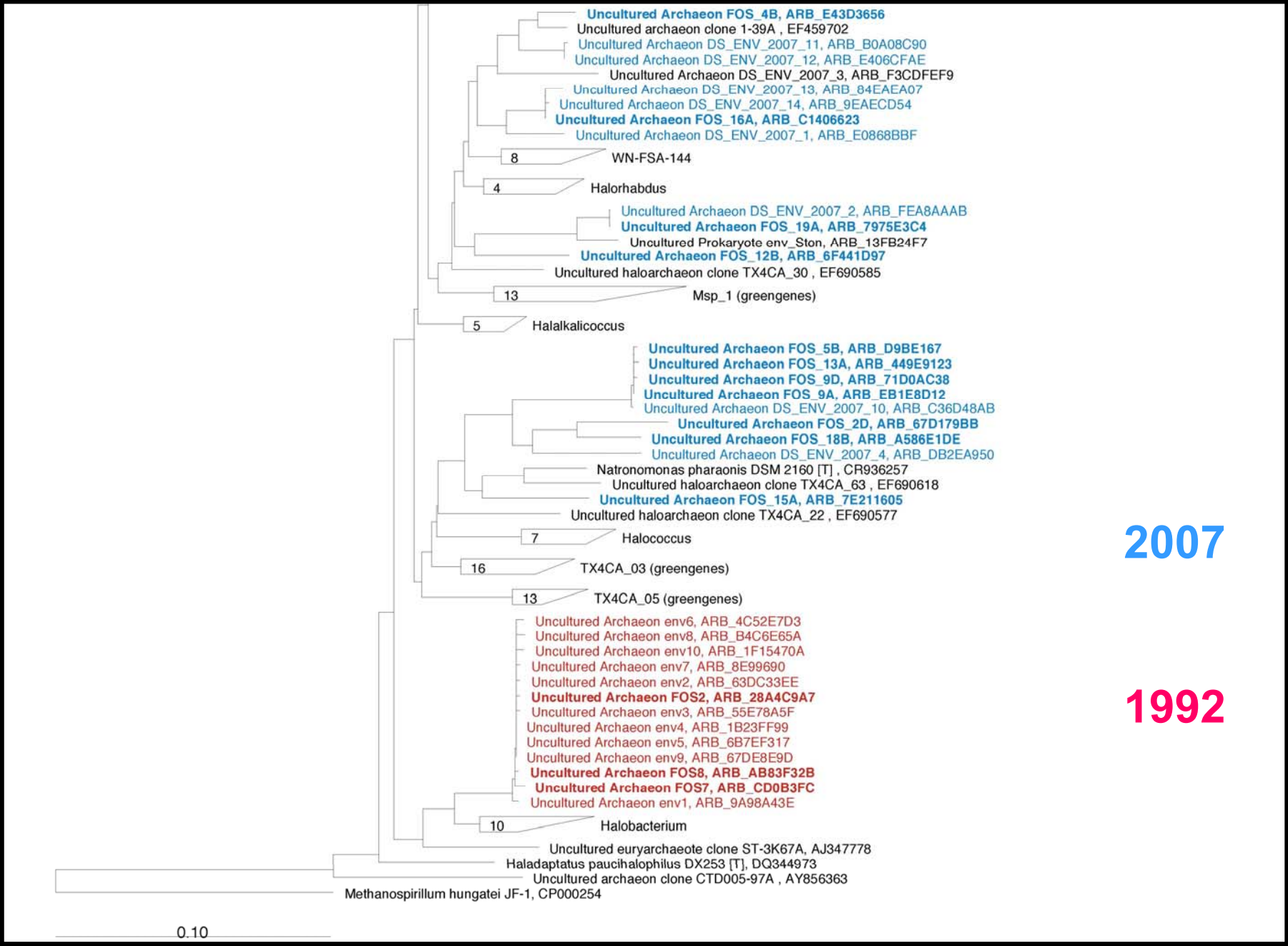
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Uncultured Archaeon DS_ENV_2007_1, ARB_E0868BBF
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WN-FSA-144
4
Halorhabdus
Uncultured Archaeon DS_ENV_2007_2, ARB_FEA8AAAB
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Msp_1 (greengenes)
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Halalkalicoccus
Uncultured Archaeon FOS_5B, ARB_D9BE167
Uncultured Archaeon FOS_13A, ARB_449E9123
Uncultured Archaeon FOS_9D, ARB_71D0AC38
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Uncultured Archaeon FOS_2D, ARB_67D179BB
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Uncultured Archaeon FOS_15A, ARB_7E211605
Uncultured haloarchaeon clone TX4CA_22 , EF690577
7
Halococcus
16
TX4CA_03 (greengenes)
13
TX4CA_05 (greengenes)
Uncultured Archaeon env6, ARB_4C52E7D3
Uncultured Archaeon env8, ARB_B4C6E65A
Uncultured Archaeon env10, ARB_1F15470A
Uncultured Archaeon env7, ARB_8E99690
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Uncultured Archaeon env3, ARB_55E78A5F
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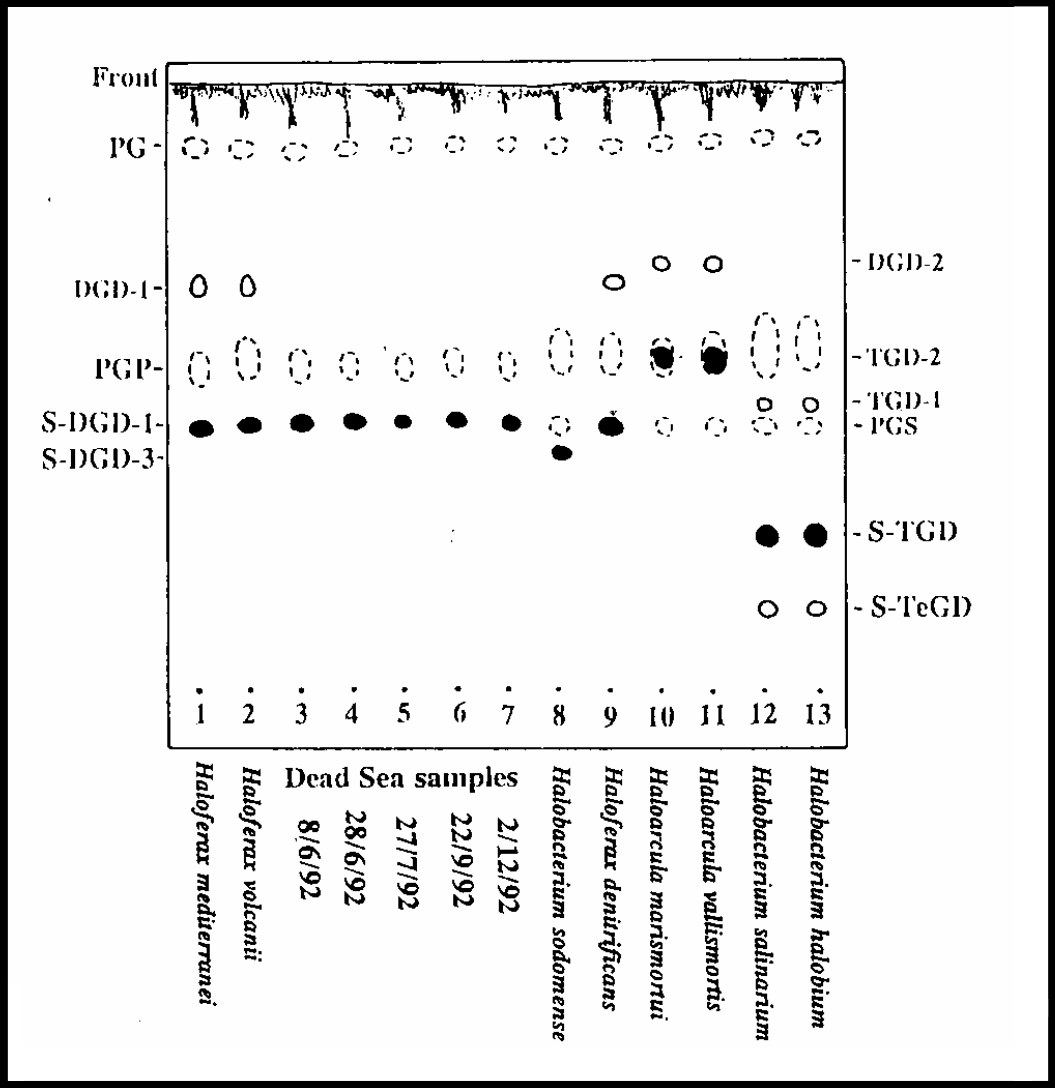
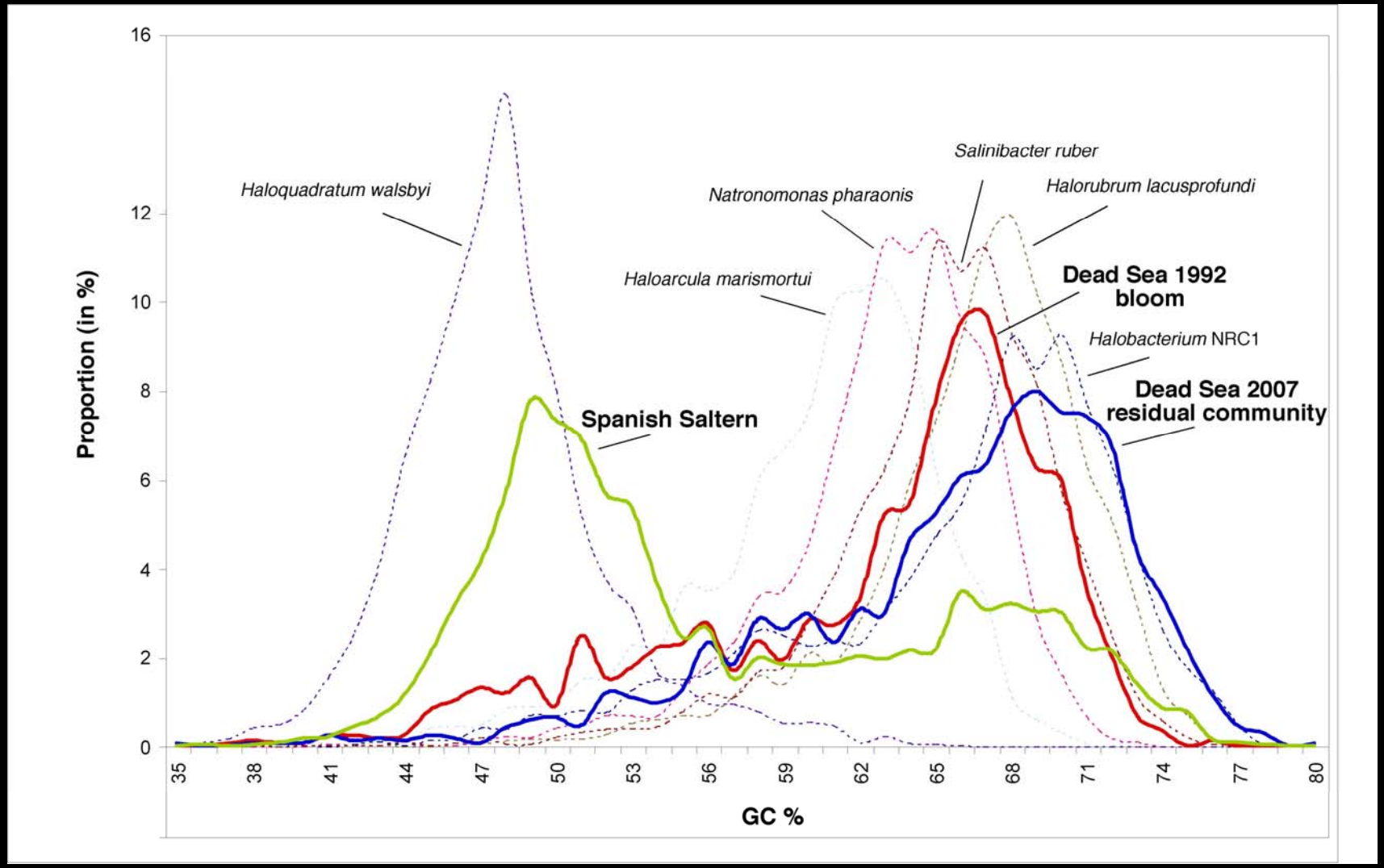
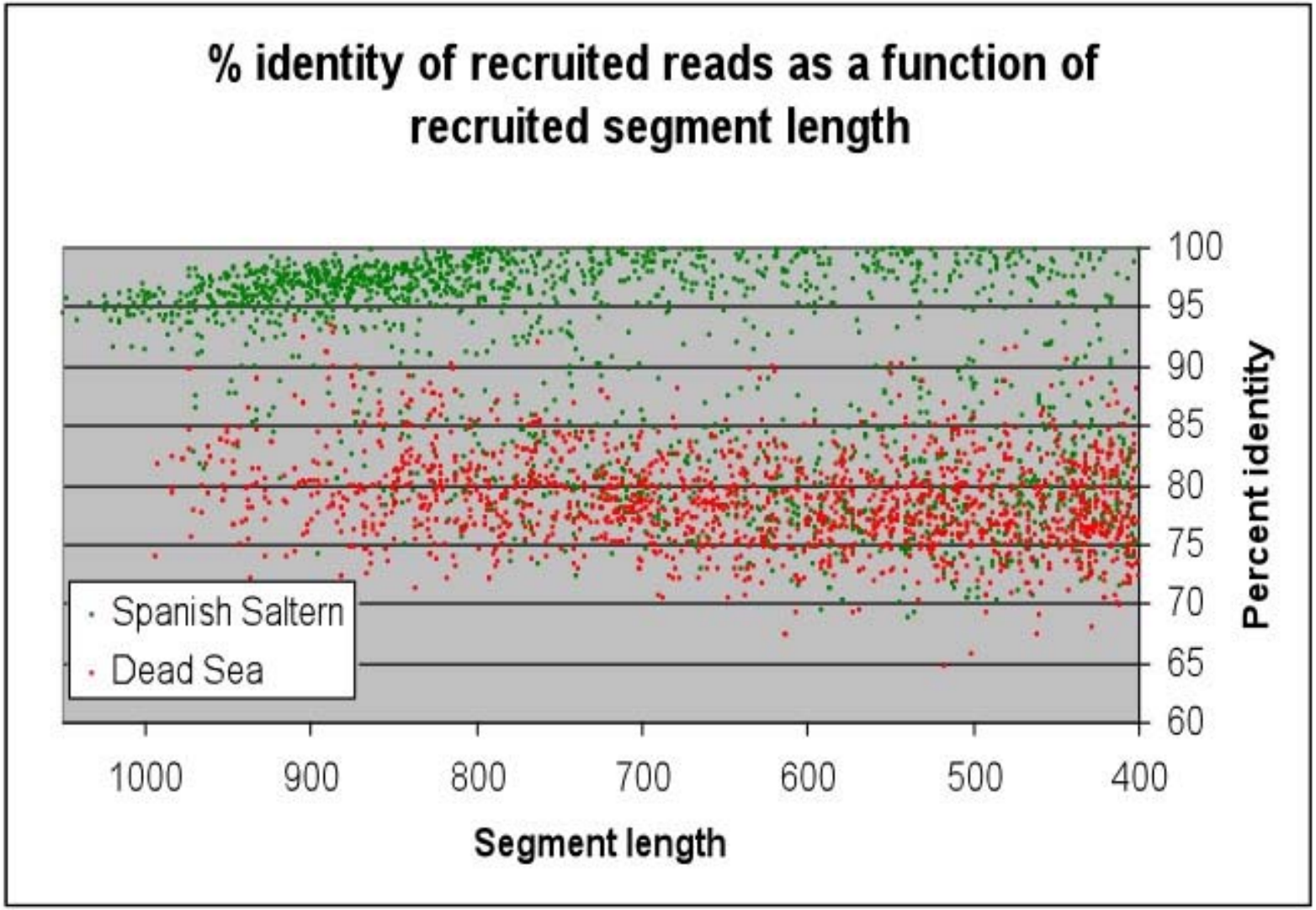
Uncultured Archaeon env5, ARB_6B7EF317
Uncultured Archaeon env9, ARB_67DE8E9D
Uncultured Archaeon FOS8, ARB_AB83F32B
Uncultured Archaeon FOS7, ARB_CD0B3FC
Uncultured Archaeon env1, ARB_9A98A43E
10
Halobacterium
Uncultured euryarchaeote clone ST-3K67A, AJ347778
Haladaptatus paucihalophilus DX253 [T], DQ344973
Uncultured archaeon clone CTD005-97A , AY856363
Methanospirillum hungatei JF-1, CP000254
0.10
2007
1992

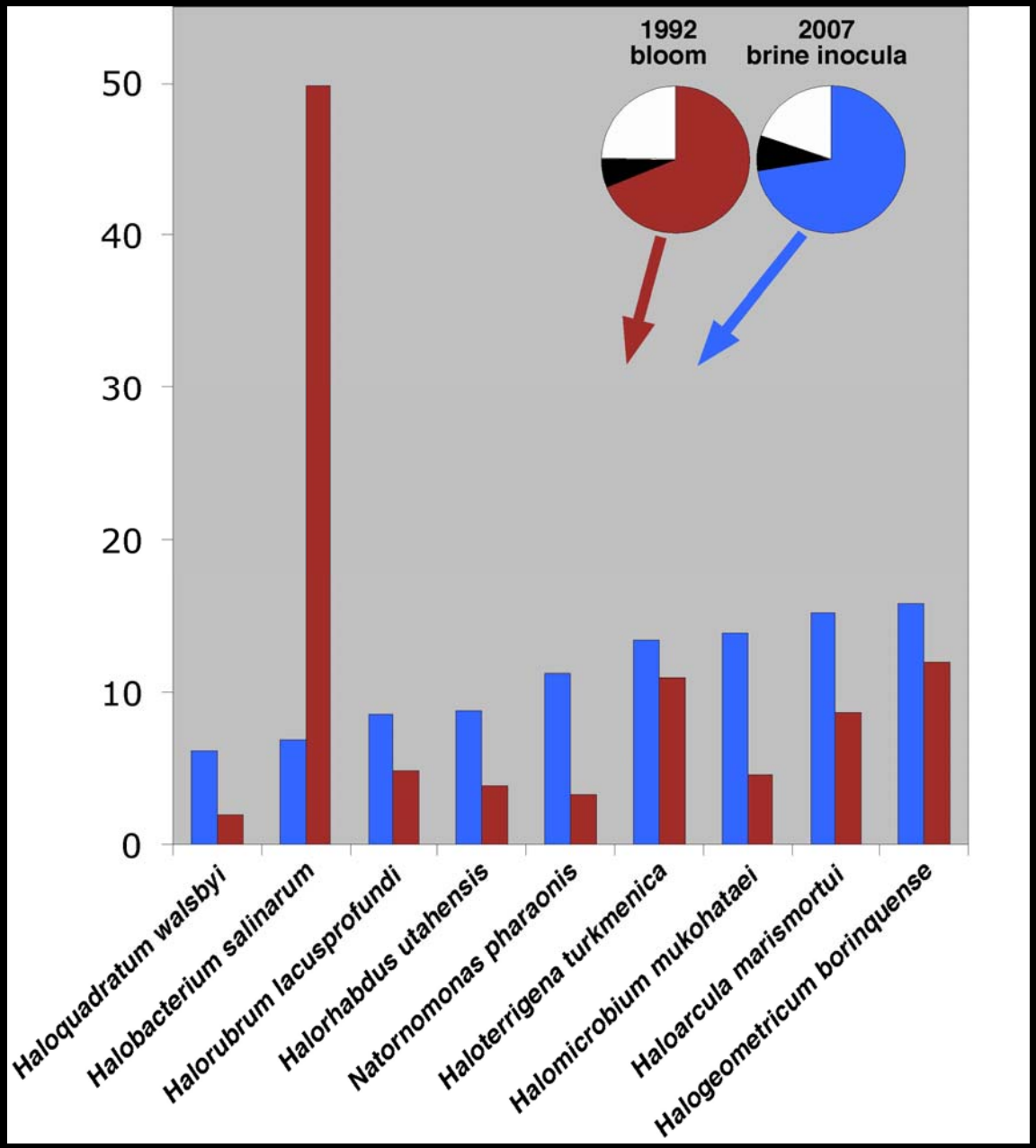
The polar lipid pattern was consistent with the genera *Halobaculum* and/or *Haloferax*





GC% distribution of Dead Sea 1992 bloom and the 2007 residual community fosmid-ends. Data for selected haloarchaeal and halobacterial genomes as well as a Spanish saltern crystallizer pond fosmid-ends are shown for reference.

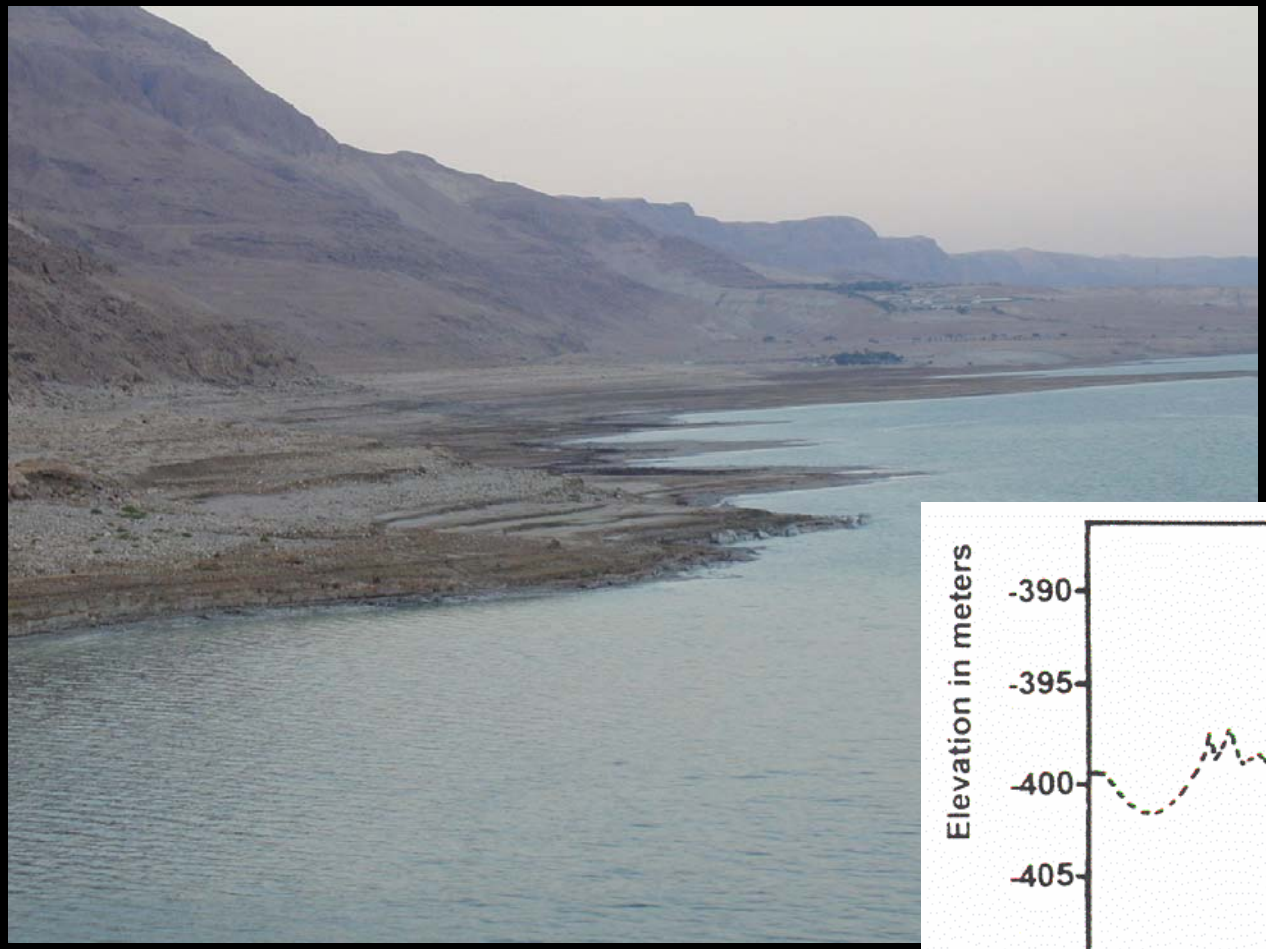

% identity of recruited reads as a function of recruited segment length
100
95
90
85
80
75
70
65
60
Percent identity
Spanish Saltern
Dead Sea
1000
900
800
700
600
500
400
Segment length

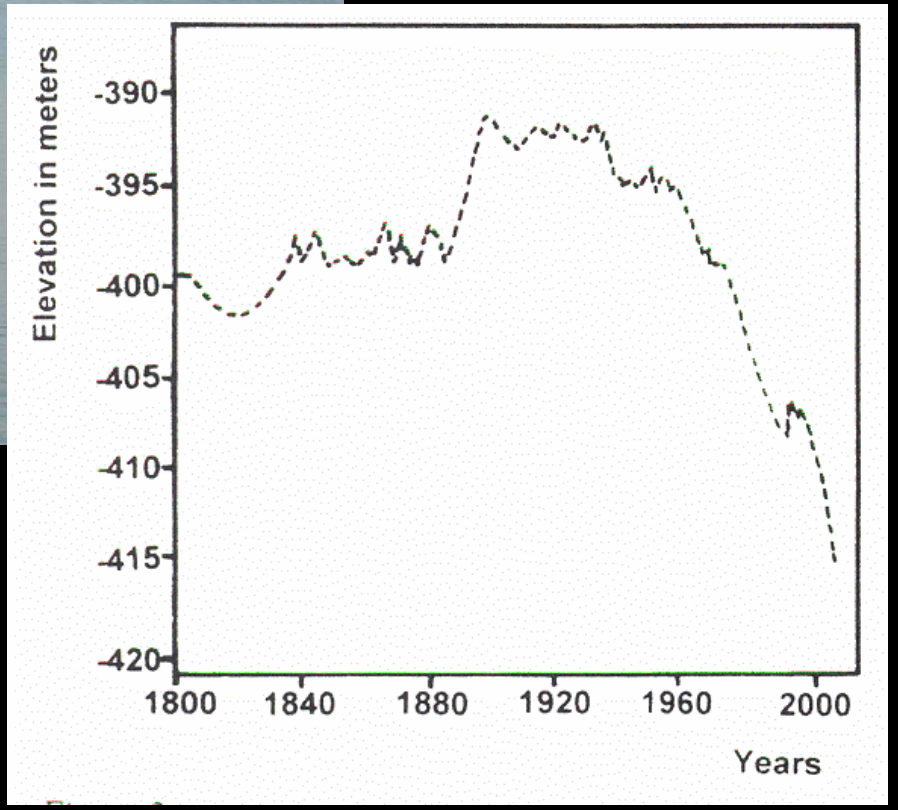


Taxon distribution of top BLASTn High Score Pairs

Top pies represent unassigned (white), bacterial (black) or archaeal (red for 1992 and blue for 2007) gene assignments

Columns represent archaeal assigned genes at the species level





The shrinking Dead Sea

Photographs: courtesy of the Tamar Regional Council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The history of the “Med-Dead” and “Red-Dead” canal plans

The first record of a planned connection between the Red Sea and the Dead Sea

(1855)

THE DEAD SEA,

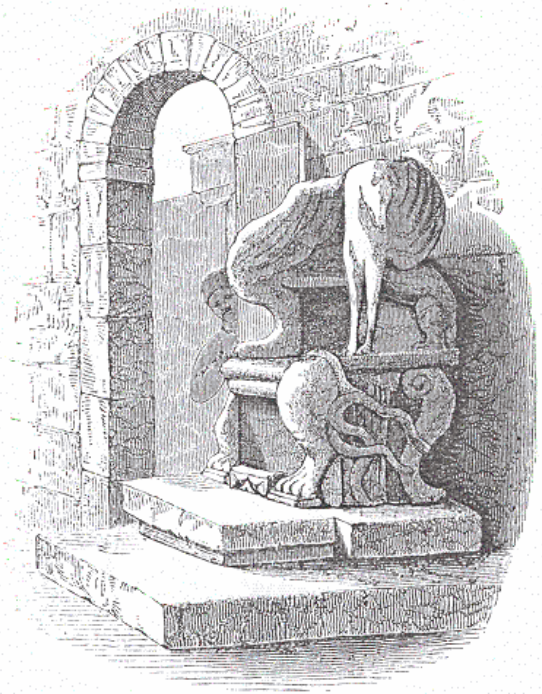
A NEW ROUTE TO INDIA:

WITH OTHER FRAGMENTS AND GLEANINGS IN THE EAST.

BY CAPTAIN WILLIAM ALLEN, R.N.

F.R.S. F.R.G.S. &c. &c.

AUTHOR OF "THE NARRATIVE OF THE NIGER EXPEDITION."



The Throne of Potamon.

IN TWO VOLUMES.—VOL. I.

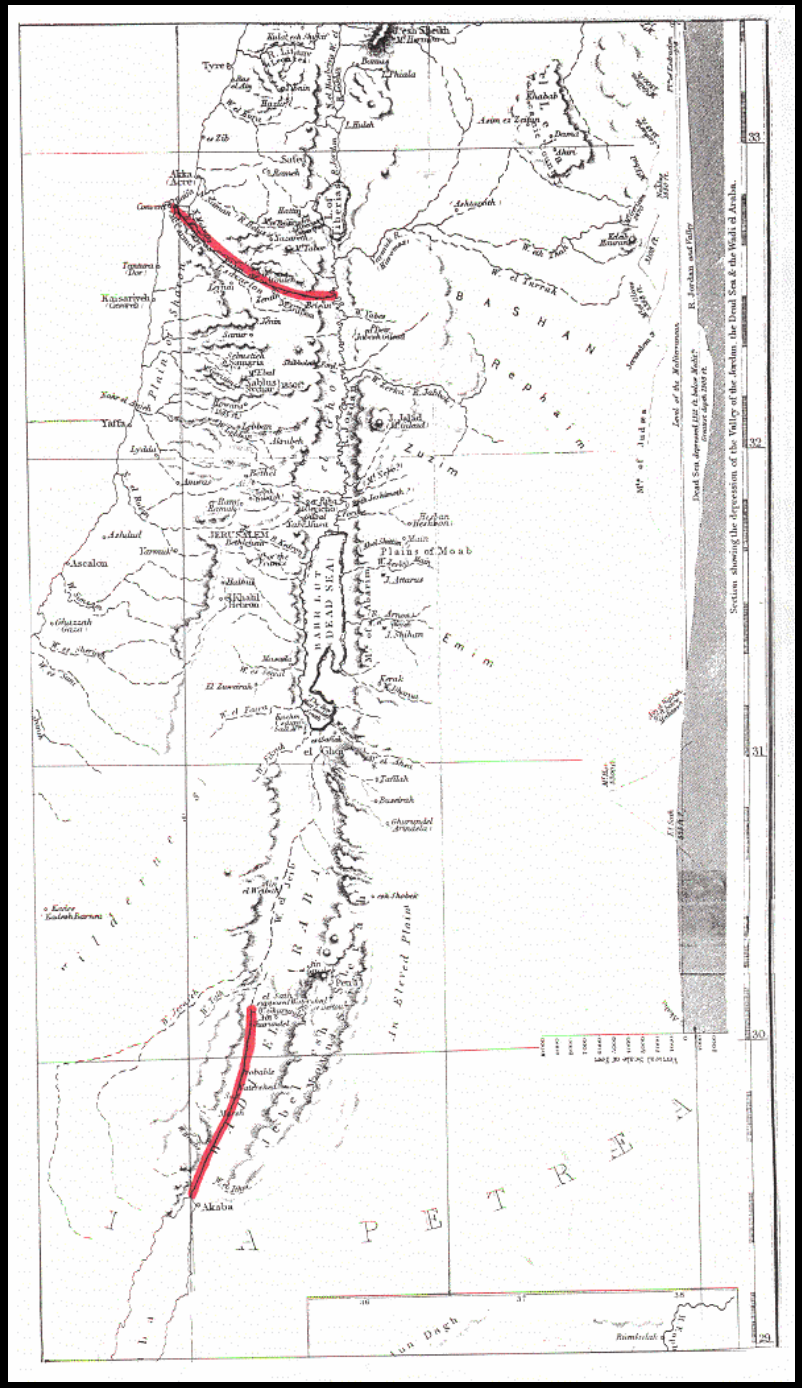
LONDON:

LONGMAN, BROWN, GREEN, AND LONGMANS.

1855.

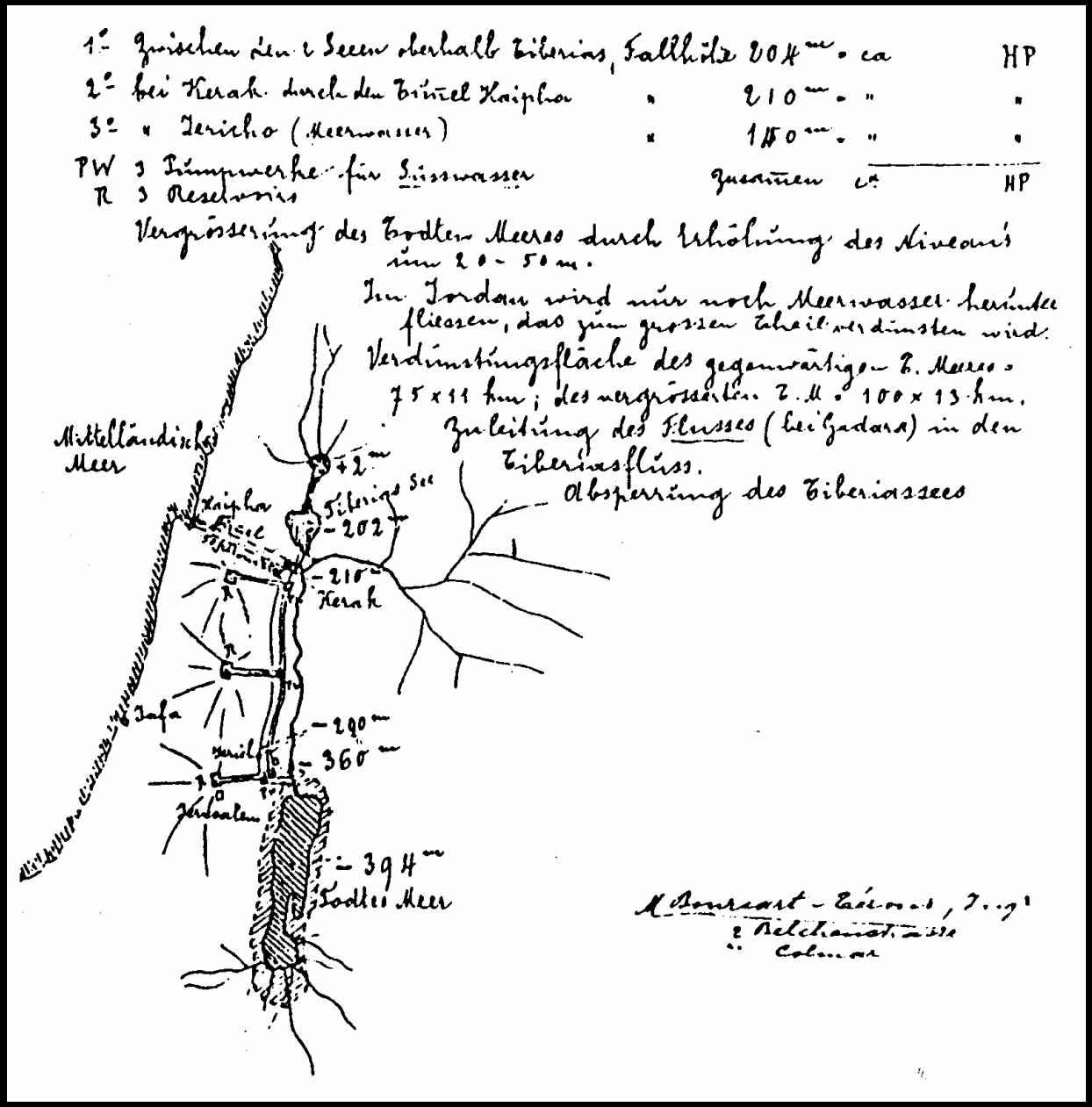
The canals proposed by Capt. William Allen in 1855

(“a new route to India”)



Sketch for a "Med-Dead" canal with hydroelectric power plant

Max Burchart, 1899



Proposed Med-Dead canal alignments

Filling stage:

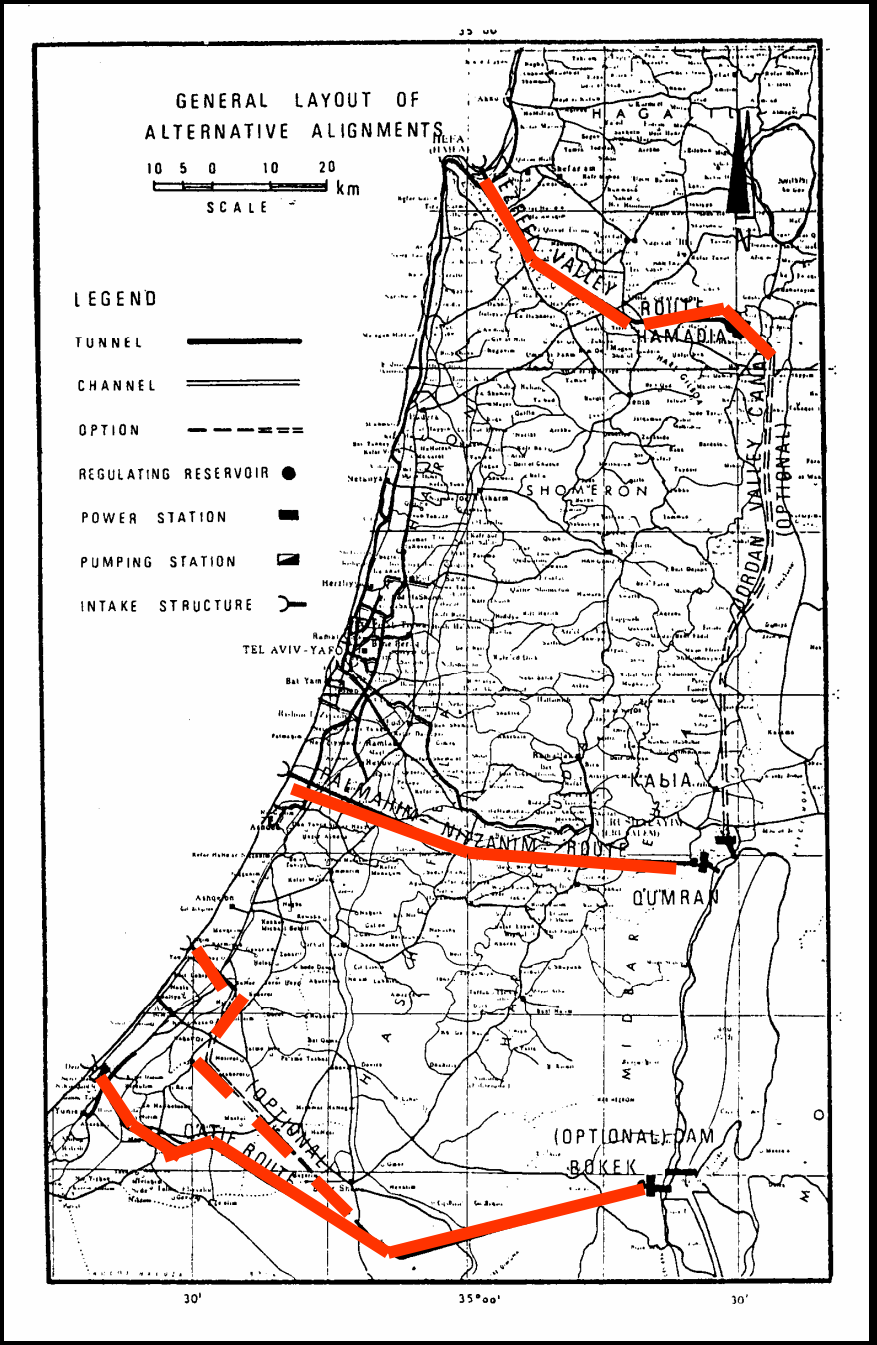
$1.6 \times 19^9\ m^3/year$

Afterwards:

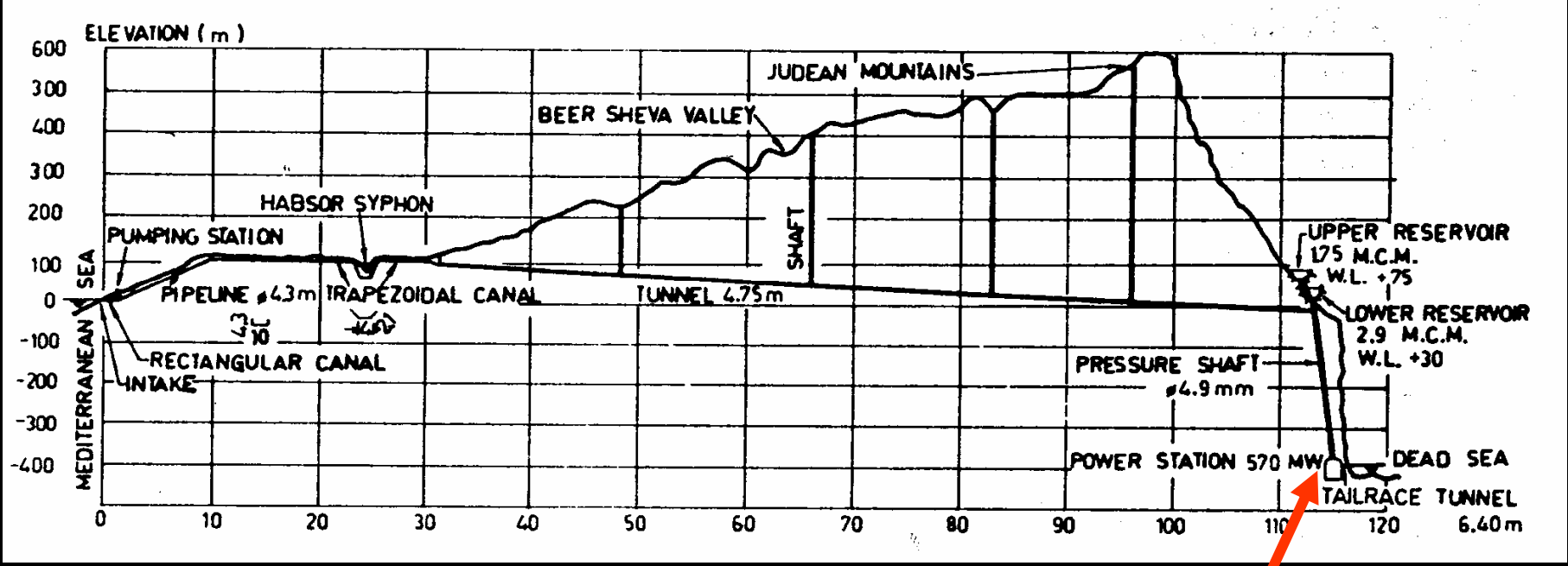
$0.95 \times 10^9 m^3/year$

Compare: National Water Carrier:

$0.4 \times 10^9\ m^3/year$



Cross-section through the proposed southern alignment

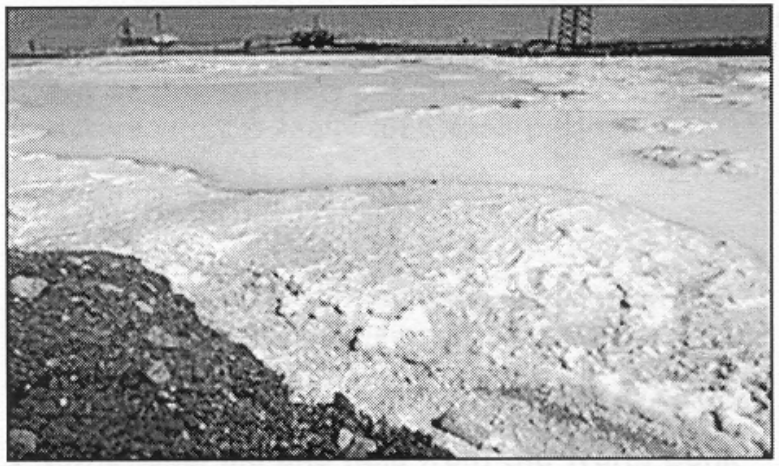


Power plant: 600-800 MW

The Johannesburg Summit – September 2002

You are in: World: **Middle East**
Monday, 2 September, 2002, 14:56 GMT 15:56 UK

Dead Sea rescue plan unveiled



Water levels are gradually falling

Israel and Jordan have agreed on a plan to build an $800 million pipeline to rescue the shrinking Dead Sea, which they share.

They propose to pipe water north from the Gulf of Aqaba in Red Sea to the Dead Sea, which is falling by about one metre (three feet) a year.

The pipeline will stretch about 320 km (200 miles), according to the plans which were announced at the World Summit on Sustainable Development in Johannesburg.

BBC NEWS – 2/9/02

Israel, Jordan announce joint Dead Sea plan

September 1, 2002 Posted: 4:04 PM EDT (2004 GMT)

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JOHANNESBURG, South Africa (AP) -- Israel and Jordan announced their largest-ever joint project at the World Summit on Sunday, a $800 million pipeline intended to save the shrinking Dead Sea from environmental devastation.

The level of the sea, shared between the two countries that signed a peace agreement in 1994, is sinking at the rate of nearly a meter (3.3 feet) a year and could disappear in a few decades, damaging tourism in both countries and indirectly draining scarce water supplies in the region, Cabinet ministers from both countries said.

"It's a catastrophe underway and it might be apocalyptic if we don't challenge it as fast as we can," Israeli Environment Minister Tzahi Hanegbi said.

The two governments said Sunday they hoped to work together to build a 300-kilometer (190-mile)-long pipeline from the Red Sea through both countries to halt the decrease in water level in the Dead Sea.

REUTERS – 1/9/02

Israel and Jordan Agree Plan to Save Dead Sea

Reuters

JOHANNESBURG - Israel and Jordan agreed a plan on Sunday to lay an $800 million pipeline to rescue the shrinking Dead Sea.

The two countries, meeting at the Earth Summit, said they would study ways to pipe water north from the Red Sea to the Dead Sea, which they share, in their biggest cooperation deal since a 1994 peace accord.

The pipeline would stretch about 200 miles and aim to help refill the sea, which is falling by about three feet a year.

CNN – 1/9/02

The proposed "Peace Conduit"

Flow: between 1.2 and 2.5×10^9 m^3/year

What will be the effect on the ecosystem?

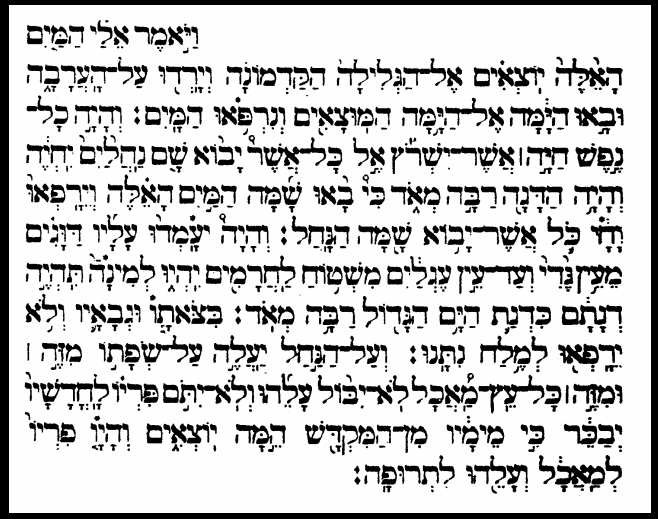
Simulation experiments in experimental ponds, in a project undertaken by the Geological Survey of Israel and The Dead Sea Works Ltd.


10

These and other simulation experiments are being continued to obtain information on the possible biological effects of the “Peace Conduit”

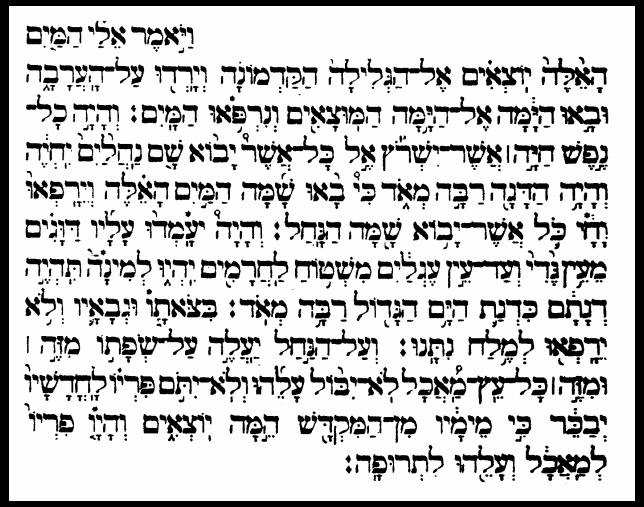
How much “alive” will the Dead Sea eventually become?

וַיֹּאמֶר אֶל־הַמַּיִם
הָאֵלֶּה יוֹצְאִים אֶל־הַגְּלִילָה הַקַּדְמוֹנָה וְיָרְדוּ עַל־הָעֲרָבָה
וּבָאוּ הַיָּמָּה אֶל־הַיָּמָּה הַמּוֹצָאִים וְנִרְפְּאוּ הַמָּיִם׃ וְהָיָה כָּל־
נֶפֶשׁ חַיָּה ׀ אֲשֶׁר־יִשְׁרֹץ אֲל כָּל־אֲשֶׁר יָבוֹא שָׁם נַחֲלִים יִחְיֶה
וְהָיָה הַדָּגָה רַבָּה מְאֹד כִּי בָאוּ שָׁמָּה הַמַּיִם הָאֵלֶּה וְיֵרָפְאוּ
וְחָי כֹּל אֲשֶׁר־יָבוֹא שָׁמָּה הַנָּחַל׃ וְהָיָה יעֲמְדוּ עָלָיו דַּוָּגִים
מֵעֵין גֶּדִי וְעַד־עֵין עֶגְלַיִם מִשְׁטוֹחַ לַחֲרָמִים יִהְיוּ לְמִינֵהֶ תִּהְיֶה
דָגָתָם כִּדְגַת הַיָּם הַגָּדוֹל רַבָּה מְאֹד׃ בִּצֹאתָו וּבְאָיו וְלֹא
יֵרָפְאוּ לְמֶלַח נִתָּנוּ׃ וְעַל־הַנַּחַל יַעֲלֶה עַל־שְׂפָתוֹ מִזֶּה ׀
וּמִזֶּה ׀ כָּל־עֵץ מַאֲכָל לֹא־יִבּוֹל עָלֵהוּ וְלֹא־יִתֹּם פִּרְיוֹ לְחָדָשָׁיו
יְבַכֵּר כִּי מֵימָיו מִן־הַמִּקְדָּשׁ הֵמָּה יוֹצְאִים וְהָיָו פִרְיוֹ
לְמַאֲכָל וְעָלֵהוּ לִתְרוּפָה׃


וַיֹּאמֶר אֵלַי הַמַּיִם
הָאֵלֶּה יֹצְאִים אֶל־הַגְּלִילָה הַמִּדְרָמוֹנָה וְיָרְדוּ עַל־הָעֲרָבָה
וּבָאוּ הַיָּמָּה אֶל־הַיָּמָּה הַמּוֹצָאִים וְנִרְפְּאוּ הַמָּיִם: וְהָיָה כָּל־
נֶפֶשׁ חַיָּה | אֲשֶׁר־יִשְׁרֹץ אֶל כָּל־אֲשֶׁר יָבוֹא שָׁם נֶחְלִים יִחְיֶה
וְהָיָה הַדָּגָה רַבָּה מְאֹד כִּי בָאוּ שָׁמָּה הַמַּיִם הָאֵלֶּה וְיֵרָפְאוּ
וְחָי כֹּל אֲשֶׁר־יָבוֹא שָׁמָּה הַנָּחַל: וְהָיָה יַעַמְדוּ עָלָיו דַּיָּגִים
מֵעֵין גֶּדִי וְעַד־עֵין עֶגְלַיִם מִשְׁטַח לַחֲרָמִים יִהְיוּ לְמִינָהּ תִּהְיֶה
דְגָתָם כִּדְגָת הַיָּם הַגָּדוֹל רַבָּה מְאֹד: בִּצְאָתָו וּבְאָיו וְלֹא
יֵרָפְאוּ לְמֶלַח נִתָּנוּ: וְעַל־הַנַּחַל יַעֲלֶה עַל־שְׂפָתוֹ מִזֶּה |
וּמִזֶּה | כָּל־עֵץ מַאֲכָל לֹא־יִבּוֹל עָלֵהוּ וְלֹא־יִתֹּם פִּרְיוֹ לְחָדָשָׁיו
יְבַכֵּר כִּי מֵימָיו מִן־הַמִּקְדָּשׁ הֵמָּה יֹצְאִים וְהָיָה פִּרְיוֹ
לְמַאֲכָל וְעָלֵהוּ לִתְרוּפָה:

(Иеекииль 47:8-11)

И сказал мне: эта вода течет в восточную сторону земли, сойдет на равнину и войдет в море; и воды его сделаются здоровыми. И всякое живущее существо, пресмыкающееся там, где войдут две струи, будет живо; и рыбы будет весьма много, потому что войдет туда эта вода, и воды [в море] сделаются здоровыми, и, куда войдет этот поток, все будет живо там. И будут стоять подле него рыболовы от Ен-Гадди до Эглаима, будут закидывать сети. Рыба будет в своем виде и, как в большом море, рыбы будет весьма много. Болота его и лужи его, которые не сделаются здоровыми, будут оставлены для соли.


וַיֹּאמֶר אֵלַי הַמַּיִם
הָאֵלֶּה יֹצְאִים אֶל־הַגְּלִילָה הַהֹלֶכֶת עַל־הָעֲרָבָה
וּבָאוּ הַיָּמָּה אֶל־הַיָּמִּים הַמּוֹצָאִים וְנִרְפְּאוּ הַמָּיִם: וְהָיָה כָּל־
נֶפֶשׁ חַיָּה | אֲשֶׁר־יִשְׁרֹץ אֶל כָּל־אֲשֶׁר יָבוֹא שָׁם נֶחָלִים יִחְיֶה
וְהָיָה הַדָּגָה רַבָּה מְאֹד כִּי בָּאוּ שָׁמָּה הַמַּיִם הָאֵלֶּה וְיֵרָפְאוּ
וְחָי כֹּל אֲשֶׁר־יָבוֹא שָׁמָּה הַנָּחַל: וְהָיָה עָמְדוּ עָלָיו דַּיָּגִים
מֵעֵין גֶּדִי וְעַד־עֵין עֶגְלַיִם מִשְׁטֹחַ חֲרָמִים יִהְיוּ לְמִינָהּ תִּהְיֶה
דְגָתָם כִּדְגַת הַיָּם הַגָּדוֹל רַבָּה מְאֹד: בִּצֹאתָו וּגְבָאָיו וְלֹא
יֵרָפְאוּ לְמֶלַח נִתָּנוּ: וְעַל־הַנַּחַל יַעֲלֶה עַל־שְׂפָתוֹ מִזֶּה |
וּמִזֶּה וְכָל־עֵץ־מַאֲכָל לֹא־יִבּוֹל עָלֵהוּ וְלֹא־יִתֹּם פִּרְיוֹ לְחָדָשָׁיו
יְבַכֵּר כִּי מֵימָיו מִן־הַמִּקְדָּשׁ הֵמָּה יֹצְאִים וְהָיָן פִּרְיוֹ
לְמַאֲכָל וְעָלֵהוּ לִתְרוּפָה:

(Ezekiel 47: 8-11)

And he said to me, “This water flows toward the eastern region and goes down into the Arabah; and when it enters the stagnant waters of the sea, the water will become fresh. And wherever the river goes every living creature which swarms will live, and there will be very many fish, for this water goes there, that the waters of the sea may become fresh; so everything will live where the water goes. Fishermen will stand beside the sea; from Ein-ge’di to En-egla’im it will be a place for spreading of nets; its fish will be of very many kinds, like the fish of the Great Sea. …. But its swamps and marshes will not become fresh; they are to be left for salt.