Optical transparency, chlorophyll and primary productivity in the Eastern Mediterranean near the Israeli coast

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ABSTRACT
For the first time, quantitative data on optical characteristics, chlorophyll standing crops and primary production are given for the pelagic waters of the Levant Basin in the Eastern Mediterranean, close to the Israeli coast. During 4 cruises (July, December 1981, April and July 1982) we measured Secchi depths ranging from 33 to 46 m, diffuse downwelling attenuation coefficients from 0.031 to 0.046 m⁻¹, near-surface chlorophylls from 0.026 to 0.069 µg L⁻¹ and photosynthetic rates from 1.62 to 9.79 mg C m⁻² h⁻¹. Images from the Coastal Zone Color Scanner on board the Nimbus 7 Satellite confirmed that these low chlorophyll concentrations were characteristic for the pelagic region and suggested that mixing with the neritic waters may occur in winter. The majority of chlorophyll and primary productivity was associated with organisms < 3 µm. Deep chlorophyll maxima (75 to 125 m) were observed at all pelagic stations. We note that these waters are among the most oligotrophic described.


INTRODUCTION
Much attention has been focused recently on the ecosystems of oligotrophic seas that constitute the majority of the world's ocean surface (Beers et al., 1982; Eppley, Peterson, 1979; Herbland, Le Bouteiller, 1981; Sharp et al., 1980; Venrick, 1982). Many basic aspects of the food web in such environments remain unclear and in

Transparence optique, chlorophylle et productivité primaire dans la Méditerranée orientale au voisinage de la côte israélienne
Nous présentons ici pour la première fois des données quantitatives concernant les caractères optiques, les concentrations de la chlorophylle et la productivité primaire dans les eaux pelagiques de la Méditerranée orientale au voisinage de la côte israélienne. Pendant quatre campagnes (juillet, décembre 1981 ; avril, juillet 1982), nous avons observé des profondeurs du disque de Secchi allant de 33 à 46 m, des coefficients d'atténuation de 0,031 à 0,046 m⁻¹, des concentrations superficielles de chlorophylles de 0,026 à 0,069 µg L⁻¹, et une activité photosynthétique de 1,62 à 9,79 mg C m⁻² h⁻¹.

Des images obtenues par satellite (Nimbus 7-Coastal Zone Color Scanner) ont confirmé que les concentrations de la chlorophylle étaient bien typiques pour le bassin du Levant. Les organismes < 3 µm étaient responsables d'une fraction importante de la chlorophylle et de l'activité photosynthétique. Les concentrations maximales de la chlorophylle ont été trouvées aux profondeurs de 75 à 125 m. Les eaux pelagiques de la Méditerranée orientale sont parmi les eaux les plus oligotrophes connues.

particular there has been considerable debate concerning the levels of primary productivity and subsequent flux patterns of fixed organic carbon (Eppley, 1980; Gieskes et al., 1979; Williams, 1981).

Although the Eastern Mediterranean has long been reported to be an area of low productivity (Sournia, 1973), quantitative data for the pelagic waters of the Levant Basin have been lacking (Filyushkin, 1962). Most of the biologically relevant information presently available for this region consists of analyses of dissolved inorganic nutrients (Al-Kholy, Waleel, 1975; Oren et al., 1973; Oren, 1970) and largely qualitative taxonomic data on net phytoplankton (Dowidar, 1974; Kimor, Wood, 1975; Lakais, Novel-Lakais, 1980), zooplankton (El Magharaby, Dowidar, 1973), ichthyoplankton (El Heihawy, Hamid, 1977; Lourie, 1972), and fish (Ben-Tuvia, 1953). The majority of these studies moreover, were limited only to neritic waters overlying the narrow continental shelf. The pioneering work of Oren (1970) in the mid 1960’s, using the 14C method (Steeman-Nielsen, 1952) to measure primary production was not continued, and his results were based on a single station about 5 km from the Israeli coast. Very recently, some new data have been published by Dowidar and Mostafa (1983) giving chlorophyll and primary productivity levels in the Egyptian offshore waters but these also apply to shallow coastal locations.

In this communication, we utilize the criteria of chlorophyll standing stocks and optical transparency to confirm that the pelagic waters of the Levant Basin close to the Israeli and Egyptian shores are among the most oligotrophic on record, with levels of primary production which also appear to be very low. Furthermore, we report that, like observations in other nutrient poor areas (Li et al., 1983), the majority of both chlorophyll and photosynthesis is associated with nano (< 20 μm) and pico (< 3 μm) phytoplankton.

STATIONS AND METHODS

The data presented here were collected during four cruises (AID-1, 23-31 July 1981; AID-2, 10-14 December 1981; and AID-3, 9-12 April 1982 on the R/V Shikmona; AID-4, 18-22 July 1982 on the R/V Nitzan) covering the area shown in Figure 1. Hydrostation locations are given in Table 1. At each station, 8 sampling depths were chosen to correspond to approximately 100, 50, 25, 12, 6, 3, 1 and 0.5% of surface irradiation which was roughly estimated by taking 3 times the Secchi depth. More accurate determinations of photosynthetically available surface and downwelling irradiances were also made with a LiCor Quantum meter. All water samples from hydrocasts were prefiltred through a 130 μm mesh Nitex net to eliminate zooplankton. For size distribution studies, samples were subsequently passed through 20 μm Nitex nets (by gravity) or 3 μm Nuclepore filters (< 100 μm Hg vacuum). Chlorophyll and phaeophytin concentrations were determined by fluorometry in discrete samples which were concentrated by filtering 250 ml through 984H glass fiber filters and extracted into 90% acetone (Holm-Hansen et al., 1965). At pigment concentration levels which were often encountered (< 0.1 μg Chl a 1-1) the precision of this technique was about ± 25%.

Surface chlorophyll was monitored between stations en route by in vivo fluorescence (Lorenzen, 1966), using a flow from the ship’s intake into a Turner Designs 10 Fluorometer. The in vivo chlorophyll fluorescence was calibrated by measuring pigments in discrete water samples taken every few hours from the fluorometer outflow and extracted as above.

Photosynthetic carbon fixation was determined by adding 14C-bicarbonate (20-30 μCi) to 130 ml glass bottles which were placed in an on-deck simulator cooled by surface water (temperatures ranging from 17.5°C on AID-3, to 28°C on AID-1). The light depths were simulated by using several layers of netting. However, did not compensate for any changes of light spectral quality which would have occurred in situ. After incubations of 4 to 6.5 hours (around local noon) the contents of the productivity bottles were filtered onto presoaked 0.45 μm Millipore filters which were then rinsed with 10 to 15 ml of filtered sea water, exposed to HCl fumes, aired and subsequently placed in scintillation fluor (Aquatol) for counting (Berman, 1973).

RESULTS AND DISCUSSION

On each cruise we observed a neritic water mass, roughly overlying the narrow continental shelf (approximately 12-15 km off Israel, see Fig. 1), with relatively lower light penetrance, high phytoplankton standing stocks and primary productivity rates. This water mass was sometimes (e.g. in July 1981) but not always (e.g. in December 1981) differentiated from the more oligotrophic water offshore by a sharp surface front of temperature and chlorophyll. In this present communication we shall deal exclusively with the offshore water (depth > 100 m) which covers the major area of the Levant Basin, and which exhibits extreme oligotrophic characteristics.

Table 1

<table>
<thead>
<tr>
<th>Station</th>
<th>Date</th>
<th>Coordinates</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-P</td>
<td>24 July 1981</td>
<td>32° 21’ 56 N 33° 28’ 52 E</td>
</tr>
<tr>
<td>1-V</td>
<td>28 July 1981</td>
<td>32° 35’ 37 N 34° 31’ 23 E</td>
</tr>
<tr>
<td>1-IX</td>
<td>30 July 1981</td>
<td>31° 56’ 38 N 32° 27’ 42 E</td>
</tr>
<tr>
<td>2-IV</td>
<td>12 Dec 1981</td>
<td>32° 25’ 00 N 32° 17’ 00 E</td>
</tr>
<tr>
<td>2-V</td>
<td>12 Dec 1981</td>
<td>32° 42’ 00 N 33° 05’ 00 E</td>
</tr>
<tr>
<td>2-VI</td>
<td>13 Dec 1981</td>
<td>32° 00’ 00 N 32° 32’ 00 E</td>
</tr>
<tr>
<td>2-VII</td>
<td>13 Dec 1981</td>
<td>32° 48’ 00 N 33° 39’ 00 E</td>
</tr>
<tr>
<td>3-III</td>
<td>9 Apr 1982</td>
<td>32° 58’ 00 N 34° 00’ 00 E</td>
</tr>
<tr>
<td>3-IV</td>
<td>10 Apr 1982</td>
<td>32° 28’ 00 N 34° 41’ 00 E</td>
</tr>
<tr>
<td>3-VIII</td>
<td>12 Apr 1982</td>
<td>32° 18’ 00 N 33° 02’ 00 E</td>
</tr>
<tr>
<td>3-VII</td>
<td>12 Apr 1982</td>
<td>32° 33’ 00 N 34° 15’ 00 E</td>
</tr>
<tr>
<td>4-IB</td>
<td>19 July 1982</td>
<td>32° 47’ 09 N 32° 27’ 02 E</td>
</tr>
<tr>
<td>4-IV</td>
<td>20 July 1982</td>
<td>31° 55’ 41 N 34° 21’ 18 E</td>
</tr>
<tr>
<td>4-VI</td>
<td>21 July 1982</td>
<td>32° 29’ 07 N 34° 39’ 01 E</td>
</tr>
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</table>
Surface chlorophyll concentrations measured in extracted samples and also estimated from in vivo fluorescence scans ranged from 0.021 to 0.083 μg.l⁻¹ for this cruise series (Fig. 2). These low values were also reflected by the average chlorophyll concentrations based on integration down to approximately 37% of surface irradiance (Tab. 2). (The anomalous high concentrations found for AID cruise 2 stations were apparently due to a systematic error in estimating the phaeopigment component of the total pigment).

Our measured chlorophyll values correspond well to some images obtained from the coastal zone color scanner (CZCS) mounted on the Nimbus-7 earth orbiting satellite (Gordon et al., 1980; Howis et al., 1980). These images are derived from an analysis of the diffusing reflected irradiance specifically due to chlorophyll pigments, mostly at depths of less than one attenuation.

Table 2
Optical transparency, chlorophyll and primary production in the Eastern Mediterranean: Secchi depth; attenuation coefficient of downwelling irradiance, K; average chlorophyll concentrations after integration to 37% of surface irradiance, Chl₃₇% ; depth of chlorophyll maximum, Z Chl₃₇%; photosynthetic carbon fixation, integrated for euphotic zone, Ps; and assimilation number; A.N. The percentages of chlorophyll and photosynthetic activity of organisms < 3 μm are given in parentheses.

<table>
<thead>
<tr>
<th>Station</th>
<th>Secchi (m)</th>
<th>K (m⁻¹)</th>
<th>Chl₃₇% (mg.m⁻³)</th>
<th>Z Chl₃₇% (m)</th>
<th>Ps (mg C.m⁻²h⁻¹)</th>
<th>A.N. (mg C.mg.Chl⁻¹h⁻¹)</th>
</tr>
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<tbody>
<tr>
<td>1-I</td>
<td>42</td>
<td>—</td>
<td>0.026</td>
<td>125</td>
<td>1.62</td>
<td>1.6</td>
</tr>
<tr>
<td>1-V</td>
<td>37</td>
<td>0.042</td>
<td>0.032</td>
<td>100</td>
<td>2.0 (98)</td>
<td>1.2</td>
</tr>
<tr>
<td>1-IX</td>
<td>41</td>
<td>0.040</td>
<td>0.024</td>
<td>125</td>
<td>3.83 (88)</td>
<td>1.4</td>
</tr>
<tr>
<td>2-III</td>
<td>—</td>
<td>—</td>
<td>0.076</td>
<td>100</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>2-IV</td>
<td>45</td>
<td>0.046</td>
<td>0.069 (82)</td>
<td>75</td>
<td>2.90 (60)</td>
<td>0.5</td>
</tr>
<tr>
<td>2-V</td>
<td>—</td>
<td>—</td>
<td>0.067</td>
<td>100</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>2-VI</td>
<td>45</td>
<td>0.044</td>
<td>0.050 (88)</td>
<td>100</td>
<td>3.31 (61)</td>
<td>1.1</td>
</tr>
<tr>
<td>2-VII</td>
<td>—</td>
<td>—</td>
<td>0.068</td>
<td>100</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>2-III</td>
<td>—</td>
<td>—</td>
<td>0.041</td>
<td>75</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>3-IV</td>
<td>—</td>
<td>—</td>
<td>0.048 (64)</td>
<td>75</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>3-VI</td>
<td>33*</td>
<td>0.031</td>
<td>0.031 (83)</td>
<td>100</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>3-VII</td>
<td>39</td>
<td>0.039</td>
<td>0.039 (60)</td>
<td>100</td>
<td>9.79 (88)</td>
<td>5.4</td>
</tr>
<tr>
<td>3-VIII</td>
<td>—</td>
<td>—</td>
<td>0.032 (66)</td>
<td>120</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>4-II</td>
<td>46</td>
<td>0.039</td>
<td>0.023 (64)</td>
<td>125</td>
<td>5.31 (76)</td>
<td>5.3</td>
</tr>
<tr>
<td>4-IV*</td>
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<td>0.039</td>
<td>0.029</td>
<td>125</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>4-VI*</td>
<td>36</td>
<td>—</td>
<td>0.039 (54)</td>
<td>125</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

* Stations 4-IV and 4-VI were sampled in the late afternoon and evening respectively.

b These percentages relate to a < 20 μm nanoplankton fraction.

Stormy conditions—probably underestimated.
Nimbus-7 orbit No. 3720, 20th July 1979, showing SE area of Levant Basin-Egyptian and Israeli coasts. Decreasing amounts of chlorophyll plus phaeopigment in the upper water column shown as intensity of white to grey-black on image.

length, i.e. the 36.8% light level (Gordon, McCluney, 1975). Nimbus-7 Orbit No. 3720 from 20 July 1979 covering the coastal area off Israel clearly shows the sharp front between neritic and deeper water masses and confirms that the low total pigment values (chlorophyll plus phaeopigment) which we measured on shipboard are characteristic in summer for most of the Levant Basin of the Eastern Mediterranean (Fig. 3). However, a further CZCS image processed recently (No. 402, 22 November 1978) indicates a more diffuse front and more complex interaction between neritic and offshore waters, with apparent meanders of higher chlorophyll shingling between the neritic to the pelagic zones (Fig. 4). As yet, we do not know what physical conditions give rise to this phenomenon and to what extent this may be typical for the early winter season. In both images much more complexity of physical structure is apparent off the Egyptian than the Israeli coast. The distinction between biological material and inorganic turbidity remains problematic in remote ocean color sensing, especially in shallow areas (e.g. the Egyptian coastal shelf) and clearly more data are required to confirm and extend the above interpretations (Gordon, Morel, 1981). Unfortunately no CZCS images taken during the period of our study (July 1981-July 1982) are available as yet.

We consistently observed the presence of deep chlorophyll maxima at depths ranging from 75 to 125 m (Fig. 5). This feature is regularly noted in oligotrophic oceans (Cullen, 1982; Schulenberger, Reid, 1981). Changes in cellular pigment concentrations can result from light adaptation by the algae and therefore these chlorophyll profiles may not accurate indicators of actual phytoplankton biomass. These deep chlorophyll peaks were found at deep (> 100 m) stations in all cruises (Tab. 2), and did not appear to depend on thermal stratification of the water column. The extent to which the phytoplankton in the chlorophyll maxima contribute to the primary productivity of the ecosystem and/or serve as a grazing resource remains to be determined.

The paucity of particulate matter in the upper water column was also shown by the Secchi readings (standard 40 cm diameter disc) and by the measured values for the downwelling light attenuation coefficient, K (Tab. 2). Although there were occasional inconsistencies between measured values for Secchi depth, diffuse attenuation coefficient, and chlorophyll concentrations, nevertheless the above data all substantiate the low particulate content and high transparency of these waters. Our Secchi values are among the highest reported for marine (Walker, 1980) or freshwater (Larson,
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1972) but similar results have been obtained in the Gulf of Eilat (Kimor, Reiss, pers. comm.).

The considerable practical difficulties which arise in measuring primary production in very oligotrophic waters, some of which were initially mentioned by Steeman-Nielsen (1952), are now generally recognized (Eppley, 1980; Gieskes et al., 1979; Williams, 1981). Measurement of extracellular release of dissolved organic carbon by the phytoplankton (Berman, Holm-Hansen, 1974) was impractical with the low photosynthetic activities which we observed. In addition, using on-deck simulator could cause artifacts of temperature and light quality during the incubation which might lead to underestimation of primary productivity. Therefore, we stress that the values for photosynthetic carbon fixation given in Table 2 should be viewed as tentative until they can be checked by other methods (Carpenter, Lively, 1980; Fitzwater et al., 1982). Estimated rates of primary productivity were extremely low, as low assimilation numbers (mg C/mg Chl/µm/s) but were similar to those reported for the Central North Pacific gyre (Sharp et al., 1980).

Despite a wide diversity of net phytoplankton (Berman, Kimor, 1983; Kimor, Wood, 1975) we found that in most cases the majority of the total chlorophyll and photosynthetic carbon fixation, could be attributed to the picoplankton (< 3 µm) fraction (Tab. 2, Fig. 3). No details are available yet concerning the species composition of the Eastern Mediterranean picoplankton populations.

The above data are limited in scope and do not permit any detailed analysis of seasonal or long term patterns of phytoplankton biomass distribution or productivity. Nevertheless, they clearly indicate that the offshore waters of the Eastern Mediterranean Basin closely resemble other extremely oligotrophic seas. The oligotrophic nature of the Eastern Mediterranean Basin results from several physical features unique to this area: 1) the general circulation is lagoonal in character with a west to east surface flow bringing relatively old, nutrient depleted water into the area (Golik, 1982); 2) the regional climate is arid with very little terrigenous runoff of nutrient-rich waters, especially since the completion in 1964 of the Aswan Dam on the Nile River in Egypt; 3) the continental shelf is narrow, particularly off Israel, allowing very little benthic-pelagic coupling for nutrient recycling; 4) the Levant Basin is a region of convergence and convective sinking of high salinity water (Wüst, 1961), especially in the winter, and this situation tends to further dilute any nutrient inputs from the coastal shelf.

On the basis of our present data and given the proximity of nearby shore based research facilities we suggest that this area will prove to be very suitable for more detailed studies of highly oligotrophic marine ecosystems.

Acknowledgements

We dedicate this paper to the memory of the late O.H. Oren who was a pioneer of Israeli Oceanographic research. This work was funded by a grant from the U.S. Agency for International Development. We thank Drs. A. Hecht, B. Kimor, N. M. Dowidar and S. Sharif El Din for constructive comments and discussions. For sampling and technical assistance we are grateful to A. Shneller, Y. Almog, Hussein Abd El Reheim and to Captain A. Zur and his crew. This is Contribution number 82029 from the Bigelow Laboratory for Ocean Sciences, and a Contribution from the Israel Oceanographic and Limnological Research Co.

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