Primary Production in the High Venice Lagoon

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Introduction

The study of the primary production of organic matter both in fresh water and in the sea is one of the main purposes of hydrology (GESSNER, 1944; KREY, 1953; STEEMANN NIELSEN, 1954; TONOLLI, 1952). In 1958–59 monthly measurements of the primary production of organic matter were made in High Venice Lagoon both at high and at low tide, following a modification of STEEMANN NIELSEN's well known ^{14}C technique (ANGOT, DOTY and OGURI, 1958; JITTS, 1957; STEEMANN NIELSEN, 1952, 1958 a; RYTHER, 1956 b; RYTHER and VACCARO, 1954).

Before examining the results, the hydrographic conditions of the Venice Lagoon may be considered in the light of recent investigations (D'ANCONA, FAGANELLI, and RANZOLI, 1951; VATOVA, 1958 a, 1958 b, 1960 a, 1960 b). At high tide, water of relatively high salinity and poor in nutrient salts enters the lagoon through the three canal gateways (see Fig. 1); at low tide the water returns to the open sea in somewhat altered conditions. It is less saline, contaminated, and full of nutrient salts originating from complex enzymatic bacterial, oxydative, and reductive processes, from the decay and partial successive mineralization of the drainage liquids and organic matter of all kinds coming from Venice with its 173,000 inhabitants and some surrounding islands as Murano, Burano, Torcello, Lido, etc.

The hydrographic conditions of the High Lagoon, and particularly the concentration of nutrient salts, undergo constant changes as they depend on the great and unceasing phenomenon of the incoming and outgoing tidal currents which are strong and rapid during the maximum tidal phase or on exceptional tides. Sea water enters the High Venice Lagoon through the canal gateway of the Lido. During the spring tides $154{\cdot}2 \times 10^6$ m^3 of sea water comes in and the lagoon then holds a total of $335{\cdot}4 \times 10^6$ m^3 of water. On neap tides the incoming water amounts to $34{\cdot}6 \times 10^6$ m^3, and the lagoon holds $77{\cdot}1 \times 10^6$ m^3. The outflow is greater on account of the 660×10^6 m^3 or so of fresh water that flows into the lagoon every year.

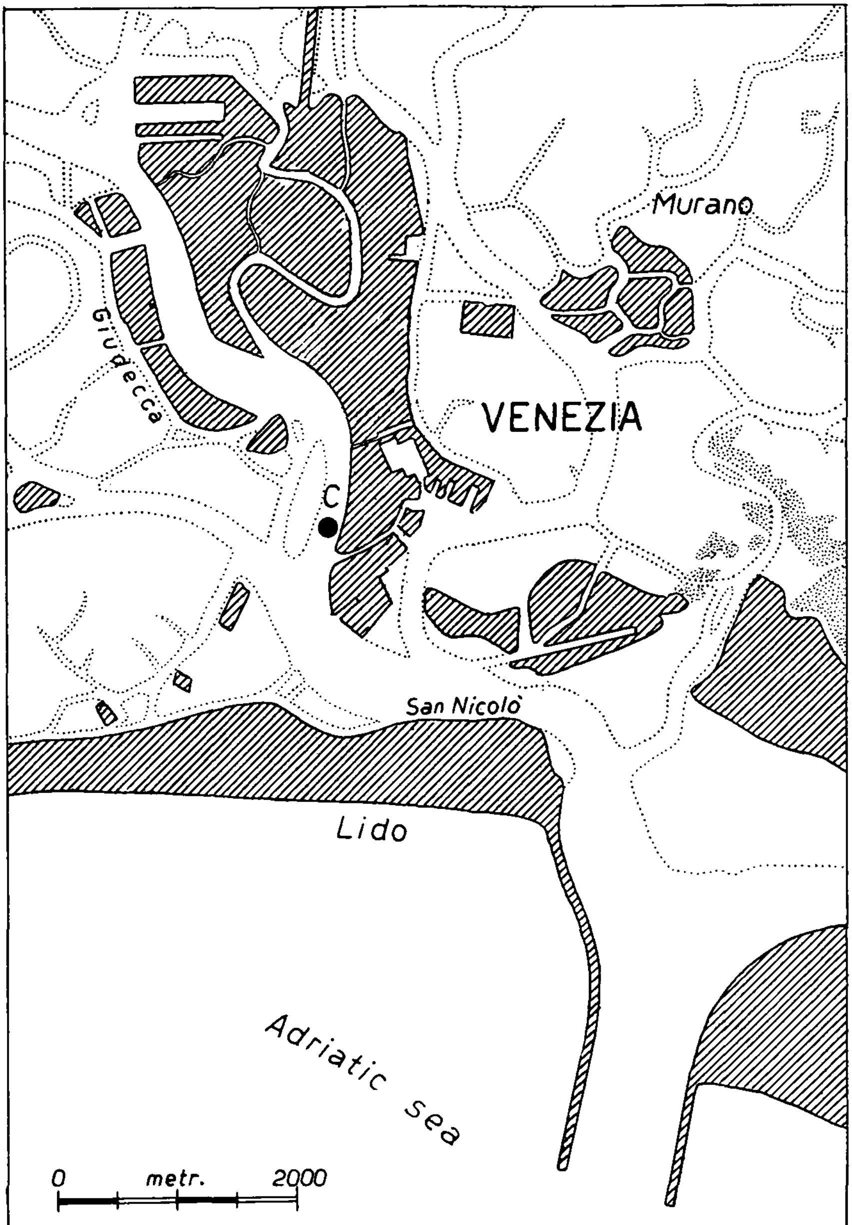

Figure 1· A chart of High Venice Lagoon showing the position of Station C at the Giardini buoy.

While a seasonal rhythm in temperature, salinity, and oxygen content can be noted both at high and at low tide, this is not noticeable in the concentration of nutritive salts because their inflow is constant. The temperature is subject to sharper oscillations than in the open sea (average temperature 6°–25°C), and the salinity is affected by the water of the rivers flowing into the North Adriatic at high tide, and by the fresh water discharged into the lagoon at low tide (average salinity 32–34·9‰). The lagoon water, which is not very deep and in constant motion, is always oversaturated with oxygen (101–105%) with the exception of the canals inside the city which have a low oxygen content.

The concentration of organic phosphorus in the lagoon is very low when the tide is coming in (1–2 mg/m³) reaching 1–4 mg and sometimes even 17 mg/m³ when the tide is receding. In the inner canals the phosphorus content reaches 137–288 mg/m³, mainly due to human metabolites.

The water of the lagoon is very rich in ammonium nitrogen (NH_4), the concentration of which varies between 12 to 29 mg/m³ at high tide and 18 to 112 mg/m³ at low tide; in the city canals where the water is full of decaying organic matter the ammonium nitrogen content reaches considerable values (377–1,069 mg/m³).

Nitrites are always present, their concentration being 3–7 mg/m³ at high tide and 4–25 mg/m³ at low tide. In the city canals the concentration is in the region of 35–37 mg/m³ in spite of the presence of high quantities of ammonia. Nitrates vary from 33 to 37 mg/m³ at high tide and from 52 to 71 mg/m³ at low tide. A relation between the concentration of nitrate and oxygen content is shown by the fact that maximum concentrations occur in the cold months (94–105 mg/m³), while in summer concentrations average 5–25 mg/m³, coinciding with the minimum oxygen values.

Silicates are present in variable concentrations which are related at high tide with river discharges and at low tide with the fresh waters that flow into the lagoon. The average concentrations are 214–440 mg/m³ and 742–753 mg/m³ in the city canals on account of the greater inflow of fresh water which is very rich in silicates.

Methods

The transparency of the lagoon waters is generally rather low (VERCELLI, 1950), increasing when new water flows in and decreasing when bad weather stirs up the bottom or when violent rain carries muddy water into the lagoon which takes on a brown-yellowish colour. The transparency measured at the Giardini buoy (St. C in Fig. 1) with Secchi discs is generally higher at high tide. In 1958–59 the average transparency was 1·4 m at low tide and 1·9 m at high tide. Consequently the photosynthetic zone (calculated by multiplying the transparency value by a factor 3·3) varies from 4·6 m to 6·3 m respectively.

In order to determine primary production water samples were drawn directly from the surface near the Giardini buoy (St. C), generally twice a month both at high tide and at low tide. Four 125 ml Jena glass bottles were filled with this water to which 1 ml of $NaH^{14}CO_3$ solution was added. Three bottles were sunk into the water and left there for two hours, at depths of 0·2, 1·0, and 2·0 m respectively, while the fourth bottle was kept in the dark for comparison. This is of importance when the water is contaminated and full of bacteria (STEEMANN NIELSEN, 1960 a). No samples were drawn from greater depths on account of both the limited extent of the photosynthetic zone and of the almost continual mixing of the water due to the tidal currents which prevent the stratification of plankton. Moreover, when the direction of the water flow is subject to continuous changes, the density and composition of the plankton population vary continuously.

The average production below unit surface is computed by multiplying the maximum rate found per volume with the depth of the photic zone and dividing by 2.

Results

According to the data collected at the Giardini buoy, the daily rate of primary production in the lagoon (see Table 1 and Figure 2, which represent the monthly production in g C/m²) increases rapidly from March (276 mg C/m²) to August (990 mg C/m²) when the surface temperature reaches its maximum values of 24·4 to 25·3°C at high tide and 24·6° to 25·7°C at low tide. In September the production decreases rapidly to 369 mg C/m², dropping to 17–133 mg C/m² in November–February, when the water temperature is 9·1°–7·3°C at high tide and 6·9°–5·4°C at low tide. In severe winters these values may fall to 1·8° and 0°C respectively.

Table 1

Organic production of water in the High Venice lagoon (Station at the Giardini buoy)

Date	Photosynthetic layer (m)		Duration of the photosynthesis (hours)	Production in mg C/m²		
	High tide	Low tide		High tide day	Low tide day	Total for the day
1958						
4. Aug.	5·1	3·0	14·2	223	687	910
13. Sept.	6·3	5·5	12·0	78	137	215
1. Oct.	4·9	6·8	11·4	28	57	85
11. Nov.	6·9	3·3	10·0	47	4	51
24. Nov.	6·7	4·1	9·0	21	8	29
1959						
30. Jan.	6·8	6·3	10·0	66	80	146
9. Feb.	6·8	4·4	10·0	27	23	50
25. Feb.	6.0	4.3	10.6	98	118	216
9. March	3·2	3·5	11·6	53	298	351
24. March	8·3	4·8	12·2	44	157	201
11. Apr.	4·0	3·4	13·2	89	332	421
24. Apr.	4·5	3·0	13·8	101	528	629
11. May	5·4	5·3	14·6	112	530	642
25. May	7·7	5·3	15·2	136	447	583
9. June	10·4	6·6	15·6	235	456	691
23. June	10·2	5·4	15·8	273	593	866
7. Aug.	11·3	4·9	14·2	313	1074	1387
22.–24. Aug.	10·8	7·1	13·8	234	360	594
15. Sept.	9·4	5·4	12·6	255	272	527
30. Sept.	3·0	4·1	11·6	53	158	211
16. Oct.	8·5	4·2	11·0	140	42	182
30. Oct.	1·6	2·2	11·0	12	–	–
30. Nov.	3·0	3·0	9·0	25	4	29
15. Dec.	3·4	2·7	8·6	10	5	15
22. Dec.	4·5	3·0	8·6	14	4	18

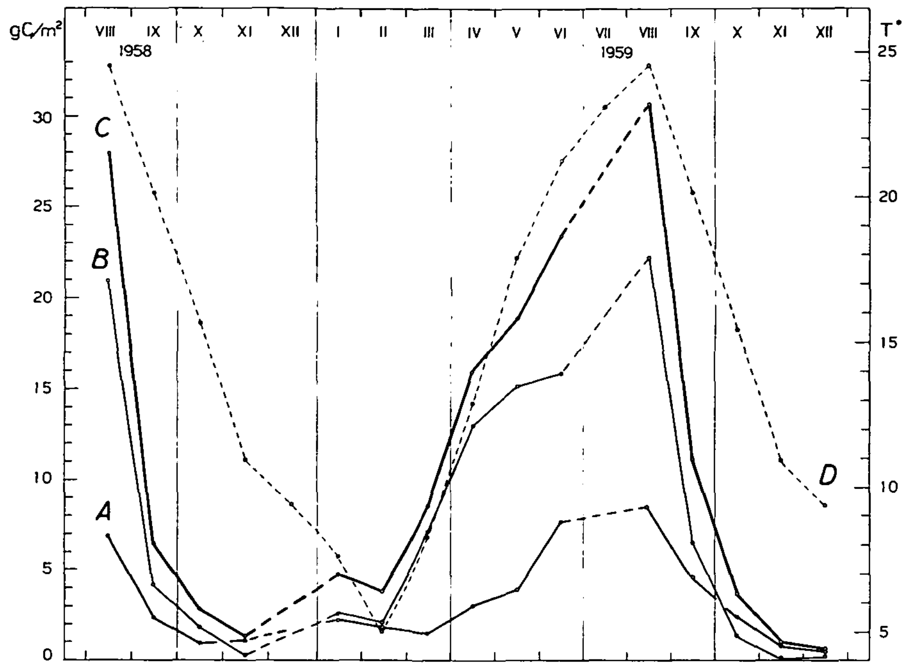

Figure 2. Monthly primary production (g C/m²) in High Venice Lagoon. (A) High tide. (B) Low tide. (C) Total production. (D) Average water temperature (1954—56).

The chief factors influencing the total daily production (high tide and low tide) therefore seem to be the temperature of the water, the duration of the assimilation which is about 10 hours in winter and 12–16 hours in spring and summer, light intensity, and the transparency of the water (RYTHER, 1956 a; STEEMANN NIELSEN, 1958 c; VOLLENWEIDER, 1956). But if we examine primary production at high and at low tide separately it is evident that from March to October production is higher at low tide than at high tide, in spite of the greater extent of the photosynthetic zone at high tide. For example, in the first 10 days of May 1959, while the photosynthetic zones have almost the same extent at high and low tide (5·4 and 5·3 m), primary production is 112 mg C/m² at high tide and 530 mg C/m² at low tide, that is almost five times greater. From the beginning of March to the end of August the total production is 29 g C/m² at high tide and 88 g C/m² at low tide, that is three times greater (maximum August values 313 and 1074 mg C/m² per day respectively). In spring and summer production is highly affected by the supply of nutrient salts, particularly of phosphates and nitrates originating from Venice and its environments. It should be added that, according to MARCHESONI (1954) and RANZOLI (1954), the amount of outgoing plankton is always smaller than the amount of incoming plankton, but the latter undergo an almost complete destruction as it proceeds from the open sea to the lagoon and consequently primary production is lower at high tide.

In the cold months, however, from September to February, the total production at low tide seems to be almost the same as at high tide, i.e. 14 and 13 g

C/m² respectively. But it should be noted that lagoon waters are more readily affected by the changes in the air temperature than the open sea, and in cold months (November–March) the water flowing in is warmer than the water flowing out, whereas in hot months (April–October) the reverse is the case.

The maximum rate of production at high tide occurs mostly at a depth of 1 to 2 m, almost never at the surface; at low tide, on the contrary, it takes place at the surface, seldom at 1 m and never at 2 m depth. Consequently, the maximum rate of production is related to the transparency of the lagoon waters.

Discussion

In the High Venice Lagoon, whose waters are rich in nutritive salts, the primary production for the year 1959 appears to be 42 g C/m^2 at high tide and 105 g C/m^2 at low tide, the total yearly production being 147 g C/m^2. If it is compared with the production in other seas (see Table 2), we shall see that, according to STEEMANN NIELSEN (1958 b), the yearly production is 39–175 g C/m^2 in the Danish waters (Sound and Isefjord) and 29–98 g C/m^2 in the Greenland coastal waters. During his cruises on the "Galathea", STEEMANN NIELSEN found that the daily production in the Pacific Ocean between California and New Zealand was 0·10–0·19 g C/m^2, while it was 0·14–0·19 g C/m^2 between Panama and the Channel (Atlantic Ocean); 0·056–0·075 g C/m^2 in the Antilles Current and 0·043–0·058 in the Sargasso Sea. The highest rate, 3·8 g C/m^2 per day, was measured in Walvis Bay at the Atlantic coast of South Africa (STEEMANN NIELSEN and AABYE JENSEN, 1957).

The average production for all oceans is about 0·15–0·19 g C/m^2 per day, that is 55–70 g C/m^2 per year and the total net production is estimated at $1{\cdot}2 - 1{\cdot}5 \times 10^{10}$ tons carbon per year (STEEMANN NIELSEN, 1960 b).

Passing on to fresh water, we shall find that yearly production is 30 g C/m^2 in the Lunzer Untersee in Austria (STEEMANN NIELSEN, 1959), about 200 g C/m^2 in Lake Furesøen in Denmark (STEEMANN NIELSEN, 1958 d) which is a eutrophic lake, and 104 g C/m^2 in Lake of Erken in Sweden (RODHE, 1958).

Table 2

Production of organic matter in different bodies of marine and fresh water

Water body	Gross production g C/m^2 per year	Author
High Venice Lagoon	147 (1959)	this paper
Danish water	39–175 (1953–56)	STEEMANN NIELSEN (1958 b)
Greenland coastal waters	29–98 (1954)	STEEMANN NIELSEN (1958 b)
Pacific	37–70 (1950–52)	STEEMANN NIELSEN and AABYE JENSEN (1957)
Atlantic	51–70 (1950–52)	STEEMANN NIELSEN and AABYE JENSEN (1957)
Sargasso Sea	18 (1950–52)	STEEMANN NIELSEN and AABYE JENSEN (1957)
Antilles Current	20–28 (1950–52)	STEEMANN NIELSEN and AABYE JENSEN (1957)
Lunzer Untersee (Austria)	30 (1953–54)	STEEMANN NIELSEN (1959)
Lake Furesøen (Denmark)	200 (1950–54)	STEEMANN NIELSEN (1958 d)
Lake Erken (Sweden)	104 (1953–56)	RODHE (1958)

From these preliminary investigations it is evident that on account of the considerable population of Venice and its environments that provide an inexhaustible mine of nutritive salts, primary production in the High Venice Lagoon is higher than in most other marine areas, being rather akin to the production in some eutrophic lakes in Europe.

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Summary

1. The primary production of organic matter in the High Venice Lagoon or Lido basin was determined through the ^{14}C technique. The extent of the photosynthetic zone was calculated by multiplying the transparency, measured with Secchi discs, by 3·3.

2. In the spring and summer of 1959 the production at low tide was about three times greater than the production at high tide, values being 88 and 29 g C/m^2 respectively, notwithstanding the smaller extent of the photosynthetic zone (4·6 m at low tide and 6·3 m at high tide). The difference is due to the presence of nutrient salts, particularly phosphates and nitrates, which originate from the decay of the drainage liquids coming from Venice and its environments.

3. In the autumn and winter of 1959, however, the production at low tide was almost the same as at high tide, values being 14 and 13 g C/m^2 respectively, owing to the lower temperature of the water at low tide.

4. In 1959 the average yearly production in the High Venice Lagoon, which is a eutrophic lagoon, was therefore higher than in most marine areas, its values being 42 g C/m^2 at high tide and 105 g C/m^2 at low tide (total yearly production 147 g C/m^2). The total net production is estimated at $1 \cdot 2 \times 10^4$ tons carbon per year.

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