ASIAN MARINE BIOLOGY 4 (1987), pp. 97–102

ULVA LACTUCA (CHLOROPHYTA, ULVALES) IN HONG KONG INTERTIDAL WATERS — ITS NITROGEN AND PHOSPHORUS CONTENTS AND ITS USE AS A BIOINDICATOR OF EUTROPHICATION*

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Abstract

The cosmopolitan green alga *Ulva lactuca* L. is often found growing in areas contaminated by domestic sewage thus reflecting its ability to thrive under such conditions. In order to study the effect of eutrophic waters on the nutrient content of the alga and its potential as an indicator species, both seawater and *Ulva* samples were collected from 10 rural and 11 urban intertidal sites around the Hong Kong Island over a period of two years. Analysis of the water samples showed that the mean dissolved inorganic nitrogen (NO_3 and NH_4) and phosphate (PO_4) levels in the rural sites were respectively 49.7 μg N l^{-1} and 6.7 μg P l^{-1}. Water samples from the urban sites contained very high mean levels of ammonia (222.4 μg N l^{-1}) and phosphate (45.3 μg P l^{-1}) reflecting the extent of sewage contamination. The amounts of tissue nitrogen and phosphorus in *Ulva* from urban areas were respectively 71 and 93% more than those in rural sites. Close correlation was found between the logarithmic concentration of seawater inorganic nitrogen and that of tissue nitrogen ($r = 0.949$). This also applied to seawater phosphate and tissue phosphorus ($r = 0.927$). It is concluded that *Ulva* is a good bioindicator of seawater eutrophication.

Introduction

Hong Kong has a land area of about 1068 km^2 and a total population of over 5.5 million. Despite Government policy to move a substantial portion of the population to new towns in the New Territories, more than 3.5 million people still live in some 60 km^2 of urban land comprising Kowloon, New Kowloon and the northern part of the Hong Kong Island. Between Hong Kong Island and Kowloon lies Victoria Harbour which has an area of about 50 km^2. Water-borne wastes from the urban population are discharged at a rate of 7.5×10^5 m^3 day^{-1} into the Harbour via 19 major seawall and submarine outfalls and over 70 stormwater drains many of which are contaminated with domestic sewage and industrial effluents (Environmental Protection Agency 1985). Although Victoria Harbour experiences strong tidal flushing, the discharge of such a vast quantity of sewage pollutes it, resulting in a general elevation of nutrients in the harbour waters and the formation of a layer of sludge on the seabed.

During several preliminary surveys on the intertidal macroalgae around the Hong Kong Island, the author found widespread occurrence and sometimes abundant growth of the green alga *Ulva lactuca* L. both within Victoria Harbour and in less eutrophicated waters on the southern part of the Island (Ho 1986a; b). This agrees with the general observation that the alga is cosmopolitan and often found in areas contaminated with domestic sewage (Sawyer 1965).

In order to assess the extent of eutrophication in the intertidal waters around Hong Kong Island, to examine how these waters affect the mineral con-

*Text of a paper delivered at the first joint meeting of the Marine Biological Association of Hong Kong and the Guangdong Society of Oceanology and Limnology and the Guangdong Society of Oceanology at Guangzhou, Peoples' Republic of China, 18–21 December 1986.

tents of *Ulva lactuca* and to investigate the feasibility of using the alga as an eutrophication indicator, a 25 month study was initiated to collect and analyse the nitrogen and phosphorus contents of seawater and *Ulva* from selected sites around the Island. Tissue nitrogen and phosphorus of the alga were found to correlate closely with the level of inorganic nutrients in the waters indicating that *Ulva* is a good indicator of eutrophication. The present paper is a report on this study.

Materials and Methods

Twenty-one sampling sites on Hong Kong Island were selected. These sites are numbered consecutively in a clockwise manner, starting from the eastern side of the Island (Fig. 1). A list of the sites is given in Table 1. Sites 1 to 10, which lie in the south and south-eastern parts of the Island, are predominantly rural and receive low nutrient loads. Sites 11 to 21 are in urban areas and are con-

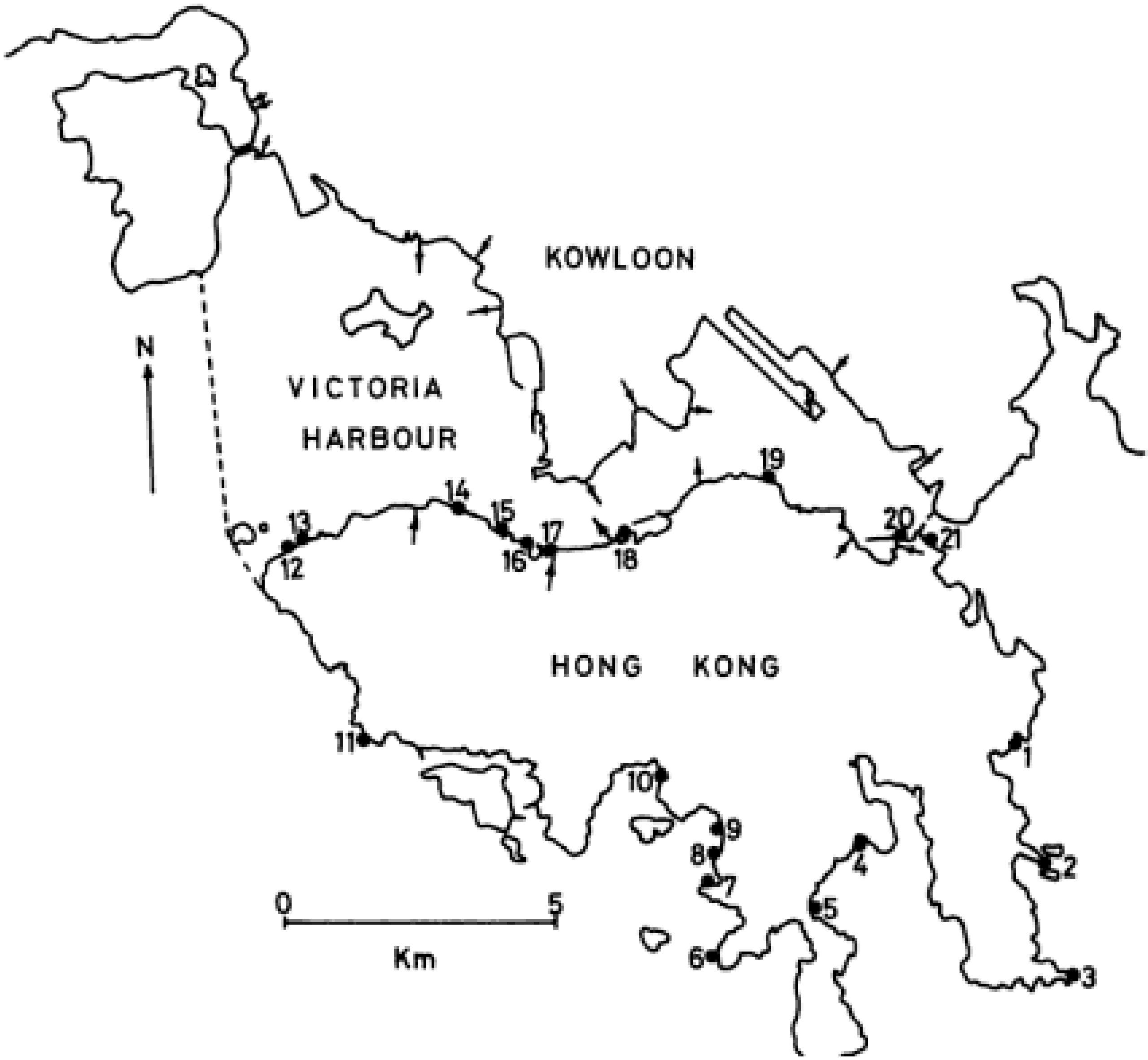

Fig. 1. Map showing the locations of the sampling sites (numbered) and the seawall and submarine outfalls (arrowed) in Victoria Harbour.

Table 1. A list of the 21 sampling sites.

Rural sites		Urban sites	
1.	Big Wave Bay	11.	Wah Fu
2.	Shek O Headland	12.	Kennedy Town West
3.	Cape D'Aguilar	13.	Kennedy Town East
4.	Turtle Cove	14.	West Arm
5.	Stanley Main Beach	15.	Blake Pier
6.	Chung Hom Kok	16.	Queen's Pier
7.	South Bay	17.	Heliport
8.	Middle Bay	18.	Kellet Island
9.	Repulse Bay	19.	North Point
10.	Deep Water Bay	20.	A Kung Ngam
		21.	Lei Yue Mun

Table 2. Chemical characteristics of seawater samples from rural (R) and urban (U) sites.

	Rural	Urban	U/R
Salinity (‰)	31.8	31.5	0.99
pH	8.3	8.1	0.98
NO_3-N (μg l^{-1})	27.1	73.6	2.72
NH_4-N (μg l^{-1})	22.6	222.4	9.84
DIN (μg l^{-1})	49.7	296.0	5.96
PO_4-P (μg l^{-1})	6.7	45.3	6.76

taminated by domestic sewage.

Monthly seawater samples at 0.3 m depth were taken from all the sites from April 1980 to April 1982. In the laboratory each sample was first measured for pH (glass/calomel combined electrode) and salinity (refractometry) before filtration (Millipore 0.45 μm) and analysis for soluble nitrate (Wood *et al.* 1967), ammonia (Strickland and Parsons 1972) and reactive phosphate (Murphy and Riley 1962). Dissolved inorganic nitrogen (DIN) in the sample is given as the sum of the nitrate and ammonia values. All nutrient levels are given as μg l^{-1}.

Ulva samples were taken, whenever available, from all sites. About 0.5 kg freshweight of the alga was harvested from each site every-time. In the laboratory each sample was cleaned of epiphytes and animals, dipped momentarily in distilled water and then dried at 105°C for 48 hours. The sample was ground to pass through a 0.75 mm sieve before subsamples were wet-ashed by a 18 M H_2SO_4: 30% H_2O_2 mixture (Allen *et al.* 1974). Each digested subsample was filtered (Whatman # 40) and the filtrate made up to standard volume with distilled water. The nitrogen and phosphorus in the filtrate were determined as ammonia and phosphate (American Public Health Association 1976) respectively. Four subsamples were analysed for each algal sample. Algal nutrient levels are expressed as mg g^{-1} dry tissue.

Results

Table 2 gives the chemical characteristics of both the rural and urban sites. The ratio between the urban and rural readings for each chemical parameter is also included.

The mean nitrate, ammonia and phosphate levels in seawater, as well as the mean tissue nitrogen and phosphorus values in *Ulva lactuca* for each site are given in Table 3.

Figure 2 is a correlation plot between the logarithmic concentration of dissolved inorganic nitrogen

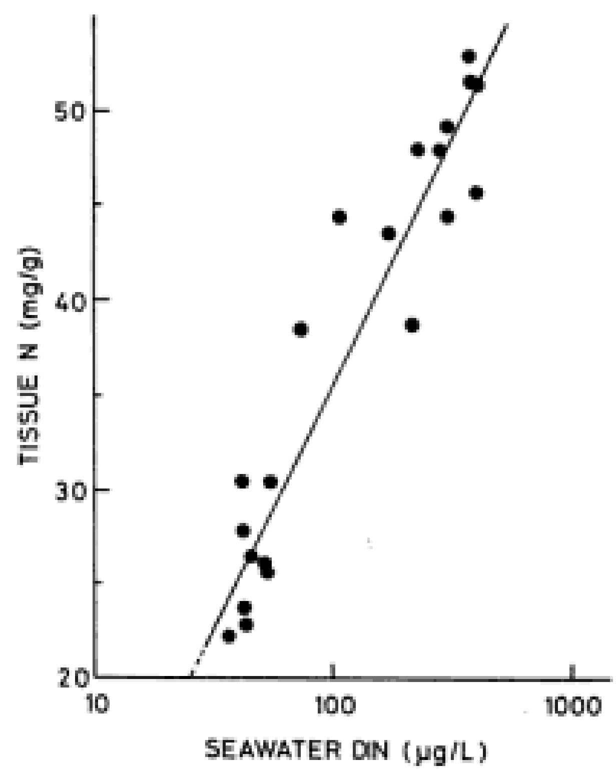

Fig. 2. A correlation plot between the logarithmic concentration of dissolved inorganic nitrogen (DIN) in seawater and tissue nitrogen in *Ulva*. r = 0.949, P<0.001.

Table 3. Mean nitrate, ammonia and phosphate levels ($\mu g\ l^{-1}$) in seawater and tissue nitrogen and phosphorus ($mg\ g^{-1}$) in *Ulva lactuca* from the 21 sites.

Site	NO_3-N	NH_4-N	PO_4-P	Tissue N	Tissue P
Big Wave Bay	39.7	35.7	11.1	38.4	1.79
Shek O Headland	18.1	25.0	6.8	30.5	1.37
Cape D'Aguilar	17.1	20.7	7.0	22.2	1.07
Turtle Cove	24.5	19.4	5.6	23.7	1.34
Stanley Main Beach	31.7	22.1	6.6	26.1	1.48
Chung Hom Kok	25.8	21.1	6.6	26.5	0.86
South Bay	24.5	20.3	5.5	22.8	1.40
Middle Bay	25.2	18.3	6.1	27.9	1.40
Repulse Bay	35.3	19.7	5.5	25.5	1.37
Deep Water Bay	29.2	23.8	6.4	30.4	1.69
Wah Fu	47.6	61.5	16.7	44.3	2.16
Kennedy Town West	51.5	127.4	34.6	43.4	3.13
Kennedy Town East	75.6	214.2	53.6	47.7	2.66
West Arm	62.5	328.4	54.5	51.4	2.80
Blake Pier	77.8	332.2	62.5	45.5	2.96
Queen's Pier	73.2	236.8	44.7	49.0	2.94
Heliport	84.3	224.2	41.8	44.3	2.48
Kellet Island	122.3	293.5	58.3	51.2	2.85
North Point	70.1	317.4	61.4	52.7	2.86
A Kung Ngam	70.4	163.6	40.5	47.8	2.76
Lye Yue Mun	73.9	147.2	29.7	38.6	1.69

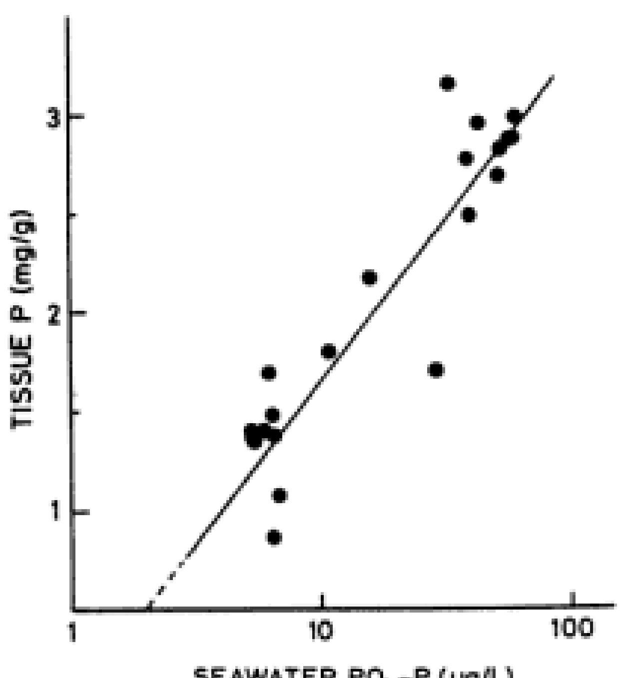

Fig. 3. A correlation plot between the logarithmic concentration of phosphate in seawater and tissue phosphorus in *Ulva*. $r = 0.927$, $P < 0.001$.

in seawater and tissue nitrogen in *Ulva*. A similar plot between seawater phosphate and tissue phosphorus is given in Figure 3.

Discussion

From the results of the chemical characteristics of the seawater samples (Tables 2 and 3) several points can be made. First, both the mean salinity and pH of the seawater in the urban sites were slightly lower than those of the rural ones. This was probably due to sewage effluent which generally has a much lower salinity and pH than seawater. Second, the inorganic nutrient levels in the seawater from the urban sites were substantially higher than those from the rural sites. This especially applied to ammonia and phosphate and is a clear sign of domestic sewage contamination. The urban to rural ratios for dissolved inorganic nitrogen and phosphate were similar, indicating that these two groups of nutrients came from the same source. Third, in the urban waters the relative amount of ammonia was much higher than that of nitrate, while somewhat similar amounts of the two were detected from the rural waters. Apparently the level of ammonia in Victoria Harbour waters has increased considerably in recent years since Watts (1973) and Hon (1978) recorded substantially lower levels of ammonia in 1971 and 1975 respectively. This provides evidence of an increase in the sewage effluent load in the Harbour over the last decade. The Environmental Protection Agency (1985) also reported that the water quality in Victoria Harbour has been declining in recent years. Fourth, sampling sites at the two ends of the Hong Kong Island bordering the Harbour, namely Lei Yue Mun and A Kung Ngam to the east and Kennedy Town West to the west, had lower levels of ammonia and phosphate in comparison with those of the more centrally located sites. Presumably this was a result of tidal dilution of the nutrients by less eutrophic seawater from outside the Harbour.

The amounts of nitrogen and phosphorus in the tissue of *Ulva* were high and greater than 20 mg g^{-1} and 1.3 mg g^{-1} (algal materials collected from Cape D'Aguilar and Chung Hom Kok were the two exceptions for tissue phosphorus) respectively. Such high nutrient levels in the alga indicated that these nutrients were unlikely to be limiting (Gerloff and Krombholz 1966; Hanisak 1979). The mean tissue nitrogen and phosphorus contents of *Ulva* from the rural sites were respectively 27.4 and 1.38 mg g^{-1}. The corresponding readings for the alga from urban sites were 71% and 93% higher at 46.9 and 2.66 mg g^{-1}. Subbaramaiah and Parekh (1966) also detected higher levels of tissue nitrogen in *Ulva fasciata* Delile grown in a sewage polluted site. Further, Guist and Humm (1976) found that *Ulva lactuca* grown in culture containing sewage effluent accumulated higher nitrogen levels in the tissue when compared with the control.

The tissue nitrogen content in the alga was strongly correlated ($r = 0.949$, $P < 0.001$) with the logarithmic concentration of dissolved inorganic nitrogen in seawater (Fig. 2). Similarly the same applied for tissue phosphorus and the logarithmic concentration of phosphate in seawater (Fig. 3; $r = 0.927$, $P < 0.001$). The high levels of tissue nitrogen and phosphorus attained by some of the *Ulva* plants indicated high nutrient uptake with excess nutrients being stored in the tissue. Further, from the shape of the two plots there was no sign of nitrogen and phosphorus saturation in the tissue (Figs. 2 and 3).

The close correlations between the nutrient levels in the alga and those in the seawater implies that the relative amounts of tissue nutrients reflected the degree of eutrophication of the waters in which the alga grew. Thus *Ulva* could be employed as a bioindicator of eutrophic coastal waters. The advantage of using *Ulva* as bioindicator is that levels of nutrients in the tissue are the results of long-term integration and accumulation of nutrients from the surrounding water, whereas the amounts of nutrients found in a seawater sample only reflect the nutrient status of the water at the time of sampling. The potential use of *Ulva* as a bioindicator is further enhanced since it possesses some desirable characteristics for an efficient indicator (Butler *et al.* 1972). These include its cosmopolitan distribution, simple morphology leading to ease of growth assessment and its graded tolerance and response to stress induced by pollutants.

Acknowledgements

The work reported in this paper was partially funded by University of Hong Kong research grant 335/021/5500. My trip to the meeting held at Guangzhou was partially funded by the Department of Botany, University of Hong Kong.

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