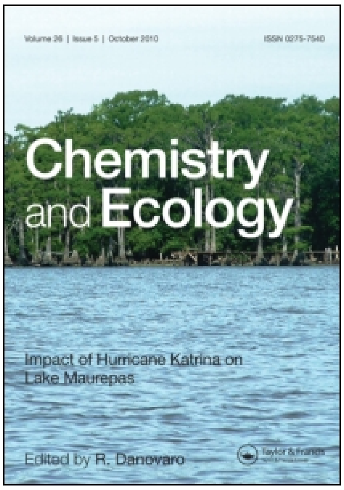

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Restoration of the Marine Ecological Environment Along the Charting Coast: Primary Productivity and Biomass Study

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RESTORATION OF THE MARINE ECOLOGICAL ENVIRONMENT ALONG THE CHARTING COAST: PRIMARY PRODUCTIVITY AND BIOMASS STUDY

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Since 1986, when green oysters occurred due to the copper and organic pollution in the Charting coastal area, the government banned all maricultural activity. It has been claimed that growing algae in a polluted environment may clean the water of pollutants and restore the marine ecosystem. To test this hypothesis, in the Charting coastal area a three-year programme (from August 1992 to July 1995) was carried out. The survey programme included environmental components such as salinity, temperature, pH, dissolved oxygen, biological oxygen demand (BOD), particulate organic carbon (POC), heavy metals and ecological indicators such as nutrients, chlorophyll-a, primary productivity. In the first year study, the environmental background data collected was used to select the suitable season and locations for growing large algae transferred from the laboratory to the field study area. Since September 1993, various species of large algae have been cultured. Although some of the growing algae were damaged by a typhoon in August 1994, the impact of the growing algae on the environmental conditions in the area has been monitored throughout. Elsewhere, we have reported that in the algae growing area higher dissolved oxygen with lower values of BOD and POC were found, and the concentrations of heavy metals in both water and sediments decreased. The purpose of this paper is to evaluate the possible impact of growing large algae on the ecological conditions in Charting coastal waters through the period from August 1983 to May 1995. As a result of the positive results obtained, large amounts of algae have again been cultured in the same area during the period from April 29 to May 25, 1995. We expect that inorganic and organic pollutants will be reduced by the algal growth, oyster mariculture will be restored and finally, the fishery resources potential will be increased.

KEY WORDS: Primary productivity, nutrients, chlorophyll-a, mariculture, mitigation of marine pollution, Taiwan.

INTRODUCTION

The coast from Kaohsiung to Tainan, including the Charting coastal area, is a very important fishery ground and oyster mariculture area in Taiwan (Su *et al.*, 1986). Due to the high concentrations of heavy metals (particularly copper) and organic pollution, mariculture in this area has been prohibited by the government since the first case of green oysters occurred in 1986 (EPA/ROC, 1990, Hung *et al.*, 1987, 1989; Hung, 1988). It is claimed that growing algae in a polluted environment may clean the water quality and restore a healthy marine ecosystem (Largo and Ohno, 1993; Aziz and Jern, 1994). To test this hypothesis, since September 1993 about 10 kg of various algal species: *Sargassum* spp., *Grateloupia filicina*, *Halymenia microcarpa*, *Padina arborescens*, *Pterocladia capillacea*, *Ulva lactuca* and *U. arasaki* have been cultured in the Charting area (22° 49′33″N, 122° 12′15″E; stations X1–X4, Fig. 1). Environmental components such as salinity, temperature, pH, dissolved oxygen and biological oxygen demand as well as heavy metals in water and sediments, and ecological factors such as nutrients, chlorophyll-a, particulate organic carbon and primary productivity have been monitored from August 1992 to May 1995. Although part of the algal crop was damaged by a typhoon in August 1994, the environmental and ecological impact of algal growth was evident. Elsewhere, Hung *et al.* (1995a) have reported and discussed the water quality changes following algal culture. The results indicated that higher dissolved oxygen (6.1–7.6 $mg\,l^{-1}$) with lower BOD (0.4–2.3 $mg\,l^{-1}$) and POC (20.6–948 $\mu g\,l^{-1}$) were observed. The concentrations of copper, zinc, lead and cadmium

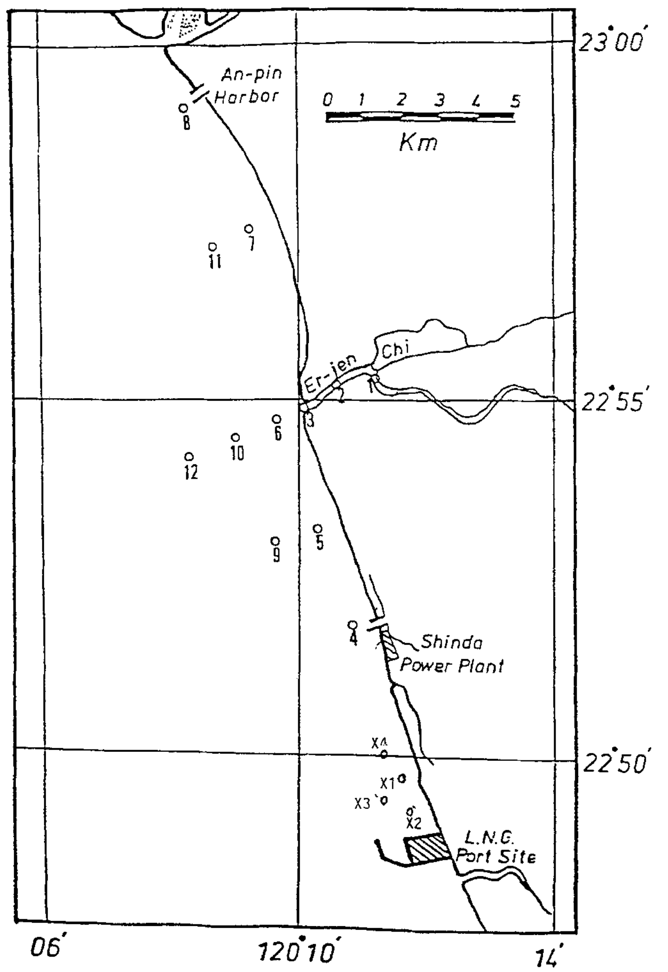


Figure 1 Sampling stations along the Erhjin Chi river (1–2), estuarine (3), the Charting coastal (4–12) and the alga cultural (X1–X4) areas in Taiwan (L.N.G.: Liquid Natural Gas).

in both water and sediments were also reduced. The purpose of this paper is to evaluate the ecological status of the Charting coastal waters before and during the culture of large algae, during the period from August 1992 to May 1995.

EXPERIMENTAL METHODS

Water and sediment samples were collected from the Erhjin Chi river and its estuary, as well as from the Charting coastal area, in twelve cruises carried out during the period September 1992 to May 1995. The sampling locations and dates are shown in Figure 1 and Table I. Water samples at different depths (0, 3, 10 and 20 metres) were collected in non-metallic Niskin bottles aboard the research vessel "Oceanic Research 1" or fishing boats. Surface sediments were collected by dredging, and then acidified to pH < 2 with nitric acid for analysis of total concentrations of heavy metals. Immediately after collection, water samples were measured for temperature, salinity, pH and analyzed for dissolved oxygen, biological oxygen demand (BOD), particulate organic carbon (as organic detritus) and heavy metals (copper, zinc, lead, cadmium, etc.) and for ecological indicators (primary productivity, biomass [as chlorophyll-a], particulate organic carbon [as phytoplankton]) and nutrients (nitrite, nitrate, phosphate and silicate). The analysis of heavy metals followed the methods described by Su *et al.* (1986), Hung *et al.* (1995b) and Hung and Meng (1992). In this paper we discuss only the ecological indicators such as primary productivity and biomass in the water.

RESULTS AND DISCUSSION

In the Charting coastal area, including the Erhjin Chi river and its estuary, chemical nutrients vary with seasons and locations, particularly during the rainy season. In southern Taiwan this is mainly contributed by storm rainfall and usually begins from March/April; the dry season begins from September/October. Figure 2 shows that an extremely high monthly average precipitation (1510.3 mm) was observed during the typhoon in August 1994. High concentrations of nitrite–N (0.98–70.7 $\mu g\,l^{-1}$), nitrate–N (< 0.7–285 $\mu g\,l^{-1}$), phosphate–P (46.1–1730 $\mu g\,l^{-1}$) and silicate–Si (309–10900 $\mu g\,l^{-1}$) were observed in the river water (stations 1 to 3) during the dry season and low values of nitrite–N (< 0.7–27.4 $\mu g\,l^{-1}$), nitrate–N (0.77–177 $\mu g\,l^{-1}$),

Table I Research cruises for hydrographical, chemical and ecological studies along the Erhjin Chi (River), estuary and the Charting coastal areas.

Cruise No.	*Date Period*	*Cruise No.*	*Date Period*
1	September 17 to 18, 1992	7	March 3 to 4, 1994
2	December 17 to 18, 1992	8	June 15 to 16, 1994
3	March 17 to 18, 1993	9	September 9 to 10, 1994
4	June 22 to 23, 1993	10	December 29 to 31, 1994
5	September 8 to 9, 1993	11	March 8 to 10, 1995
6	December 30 to 31, 1993	12	May 24 to 25, 1995

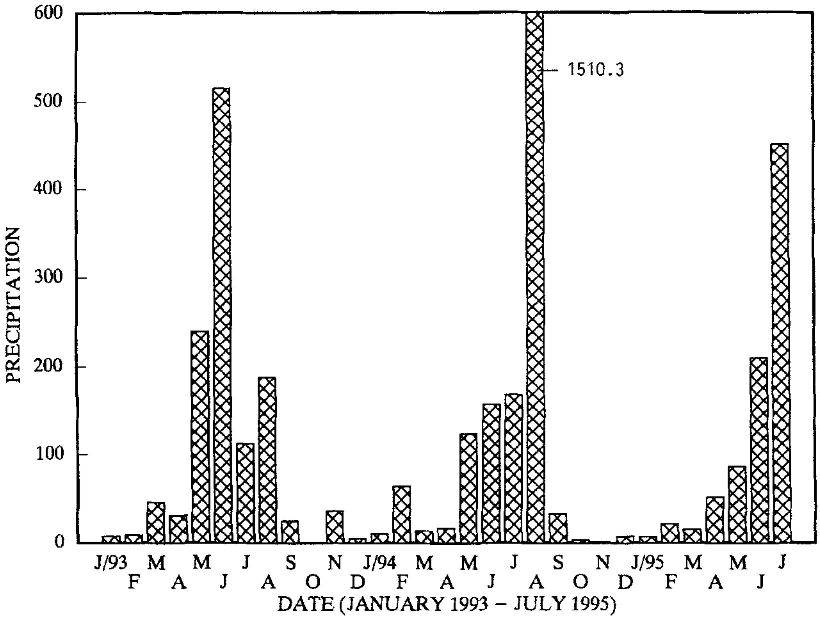


Figure 2 Monthly average values of precipitation (mm) along the Erhjin Chi (River) and the Charting coastal areas.

phosphate–P (0.8–188 μg l^{-1}) and silicate–Si (10.2–926 μg l^{-1}) in the coastal sea water (stations 4 to 12 and stations X1 to X4) immediately after the rainy season (Figs. 3 to 6). Relatively lower concentrations of nutrients, particularly nitrite and phosphate, were found in the area of algal culture (stations X2, X3) compared with those found in the coastal water (stations 4 to 12).

Figure 7 shows the seasonal and regional distribution of chlorophyll-a in the water column from 0 to 20 metres along the Charting coastal area. In general, higher values of chlorophyll-a (0.09–12.4 μg l^{-1}, mean 2.37 ± 2.35 μg l^{-1}) were found at nearshore stations (4 to 8) compared with those (9 to 12) offshore (0.07–8.37 μg l^{-1}, mean 1.52 ± 1.77 μg l^{-1}). Unfortunately, no chlorophyll-a determinations were made in the algal culture area before August 1993. However, lower values of chlorophyll-a (0.47–2.15 μg l^{-1}, mean 1.11 ± 0.50 μg l^{-1}) were found at stations X1 to X4 during the period from September 1993 to March 1994, compared with those found from September 1994 to May 1995 (0.08–4.13 μg l^{-1}, mean 1.48 ± 1.34 μg l^{-1}). Elsewhere, we noted (Hung *et al.*, 1995a) that although some of cultured algae were damaged by typhoon experienced in August 1994, the impact of growing algae was still evident. Steps were taken to transfer large amounts of algae from the laboratory to the same area on April 29, May 12 and May 25, 1995 to re-establish the field cultures. Preliminary results strongly indicate a higher chlorophyll-a (3.21–4.13 μg l^{-1}, mean 3.68 ± 0.33 μg l^{-1}) in the regrowth area on May 25, 1995, as shown in Figure 7.

The measurement of chlorophyll-a is one of the methods used to estimate primary productivity. Raymont (1980) considered that the ratio of carbon and chlorophyll-a, a

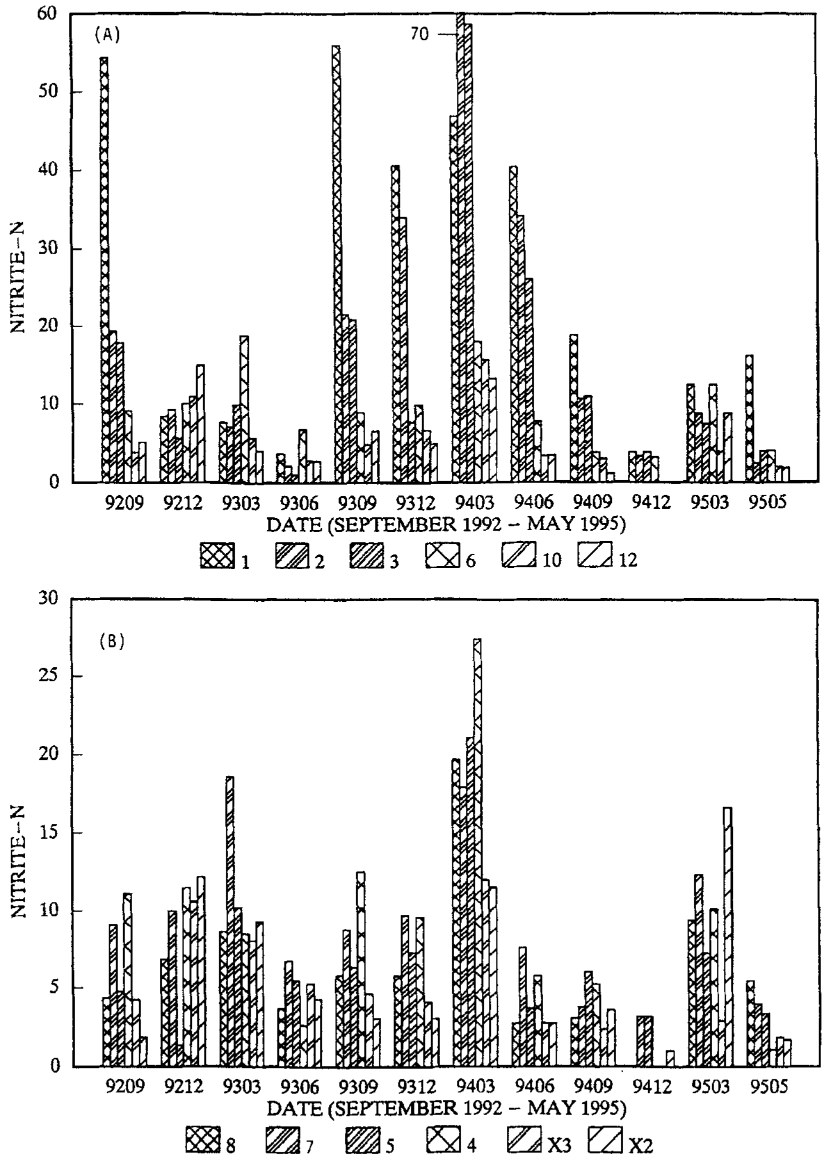
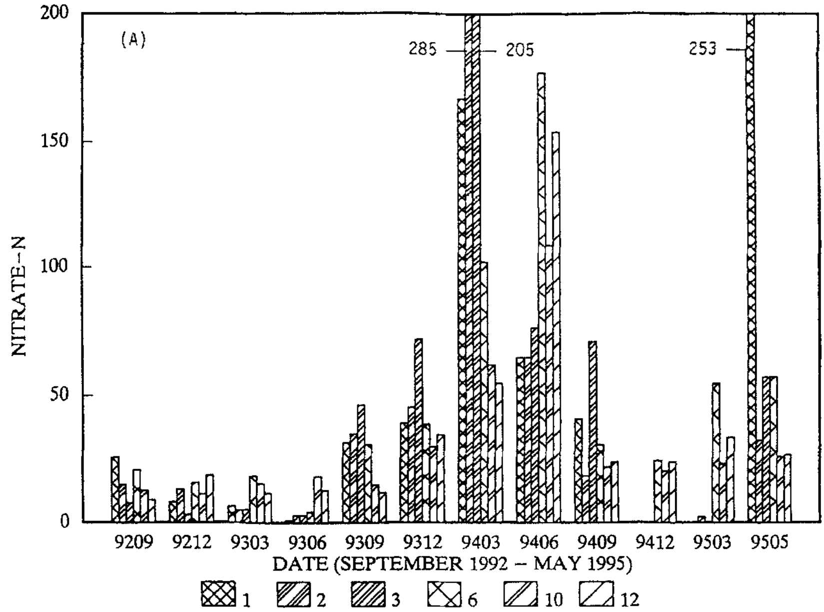


Figure 3 The distribution of nitrite–N (μg l^{-1}) in water collected along the Erhjin Chi stations (river, 1–2; estuary, 3), Charting coastal (4–12), and the algal cultural (X2–X3) areas (A, Stations 1, 2, 3, 6, 10 and 12; B, Stations 8, 7, 5, 4, X3 and X2).

measure of phytoplankton biomass, is 13.6 to 17.3 (mean 15.4), i.e. 1 μg chlorophyll-a is equivalent to 15.4 μg POC of phytoplankton. Table II indicates that particulate organic carbon in the phytoplankton (POC-P) ranged from 1.08–191 μg l^{-1} (mean 30.9 ± 28.1 μg l^{-1}) in coastal water, while in the algal growing area values of POC-P were in the range 7.2–33.1 μg l^{-1} (mean 16.9 ± 6.5 μg l^{-1}) in the period September 1993



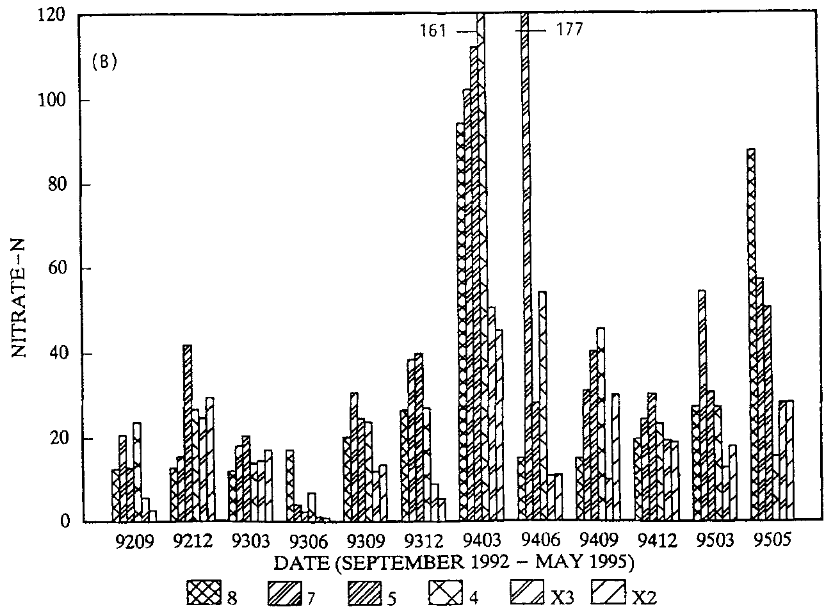
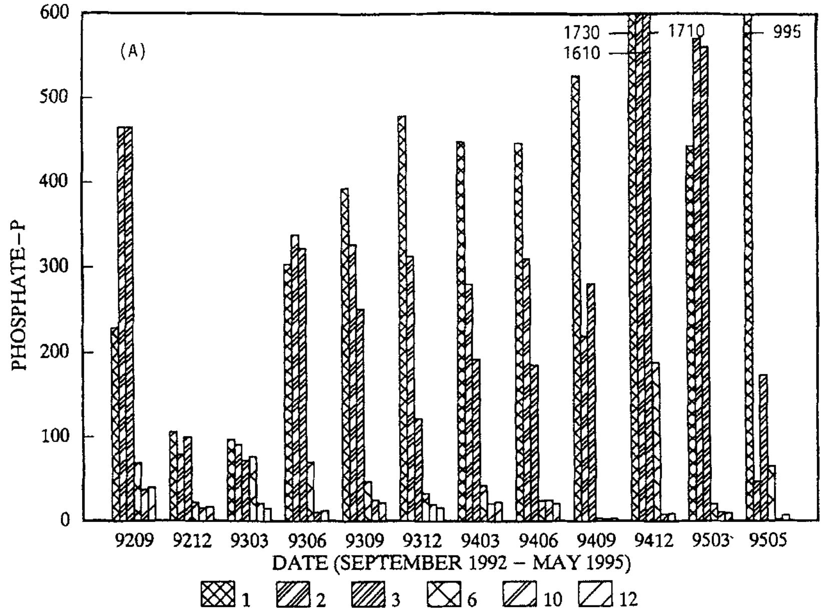


Figure 4 The distribution of nitrate–N (μg l^{-1}) in water collected along the Erhjin Chi stations (river, 1–2; estuary, 3), Charting coastal (4–12), and the algal cultural (X2–X3) areas (a, Stations 1, 2, 3, 6, 10 and 12; **B**, Stations 8, 7, 5, 4, X3 and X2).



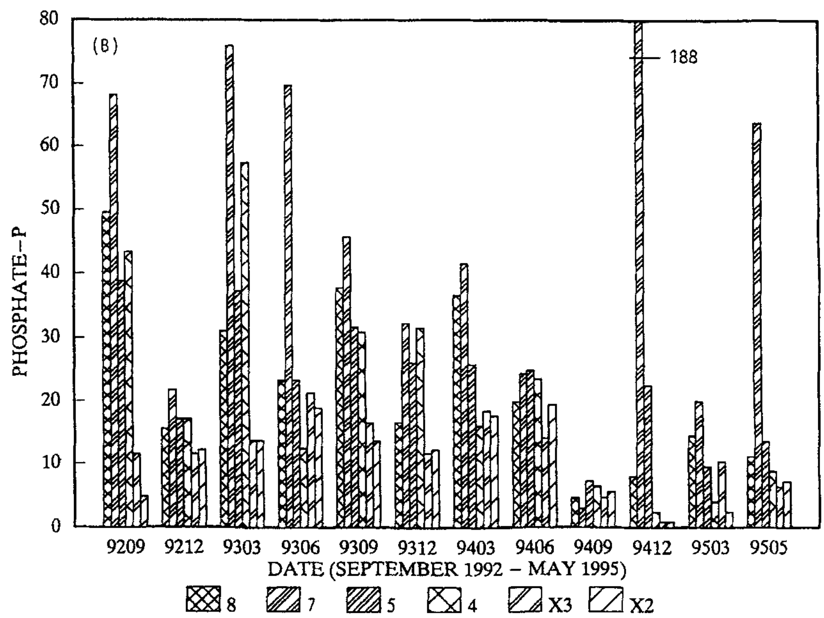
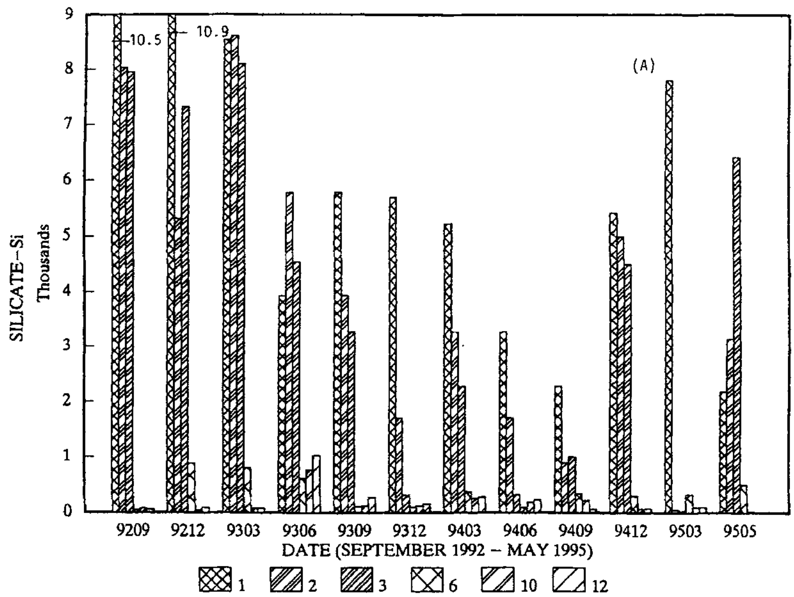


Figure 5 The distribution of phosphate–P (μg l^{-1}) in water collected along the Erhjin Chi stations (river, 1–2; estuary, 3), Charting coastal (4–12), and the algal cultural (X2–X3) areas (A, Stations 1, 2, 3, 6, 10 and 12; B, Stations 8, 7, 5, 4, X3 and X2).



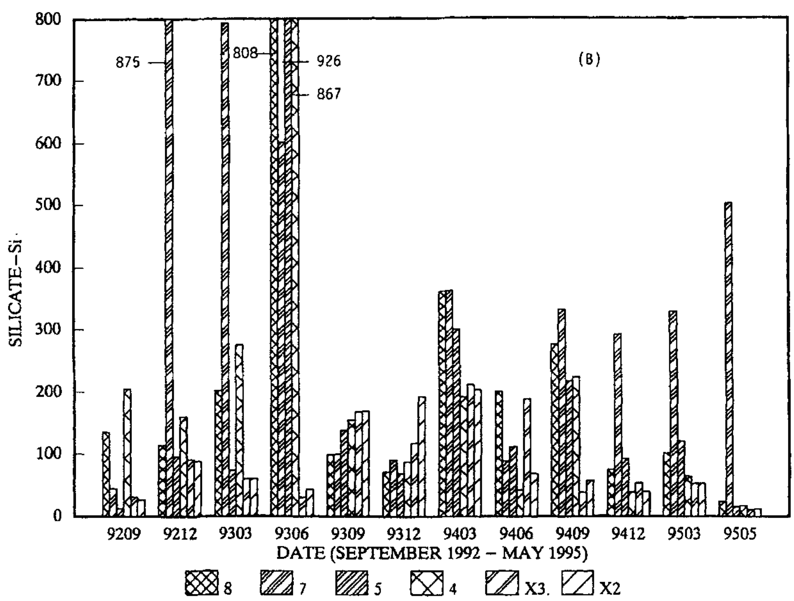


Figure 6 The distribution of silicate–Si (μg l^{-1}) in water collected along the Erhjin Chi stations (river, 1–2; estuary, 3), Charting coastal (4–12), and the algal cultural (X2–X3) areas (A, Stations 1, 2, 3, 6, 10 and 12; B, 8, 7, 5, 4, X3 and X2).

to June 1994. After the extensive restocking of algae between April 29 to May 25, 1995, very high values of POC-P were found, ranging from 49.4–63.6 μg l^{-1} (mean 54.7 ± 5.8 μg l^{-1}).

Huang (1995) studied the standing crop in the algal culture area and found similar results with higher standing crops in the period from August 1994 to July 1995,

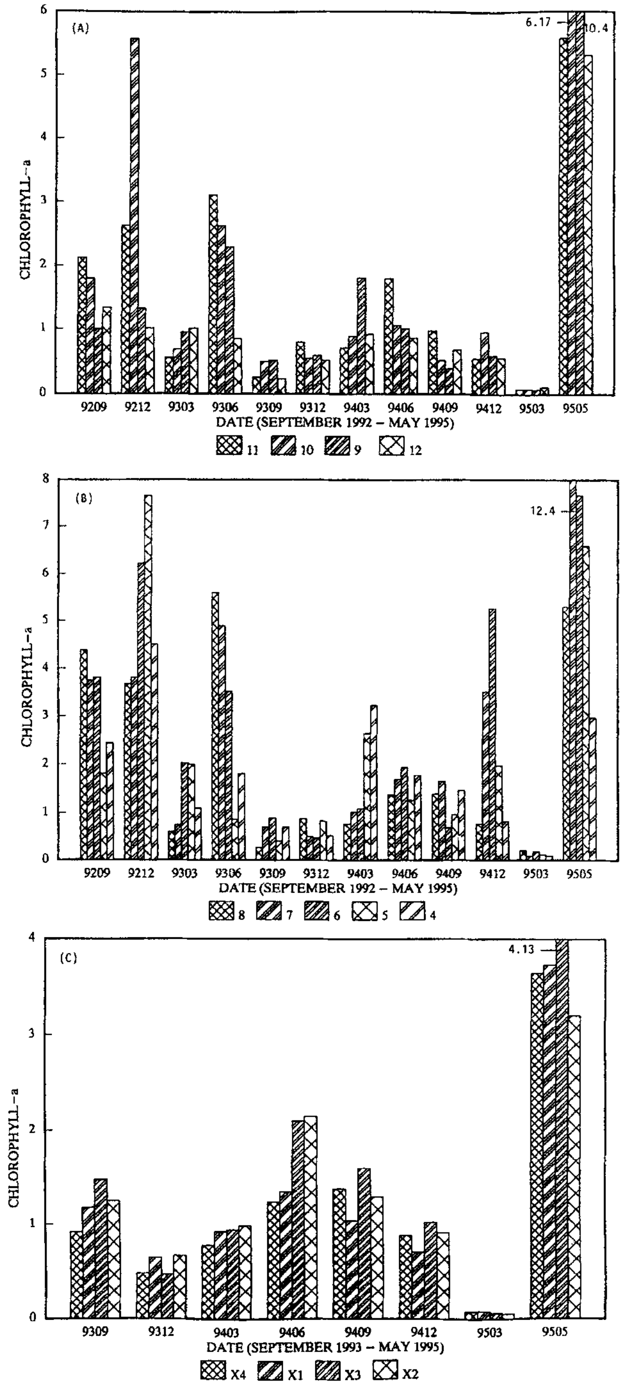


Figure 7 The distribution of chlorophyll-a (μg l^{-1}) in water collected along the Charting nearshore (4–8) and offshore (9–12) including the algal cultural (X1–X4) areas (A, Stations 9, 10, 11 and 12; B, Stations 4, 5, 6, 7, and 8; C, Stations X1, X2, X3 and X4).

Table II Particulate organic carbon (μg l^{-1}) in phytoplankton (POC-p) and organic detritus (POC-d) in the Charting coastal waters*.

Station	*POC-p*	*POC-d*	*POC-p*	*POC-d*	*POC-p*	*POC-d*	*POC-p*	*POC-d*
	Sept. 1992		Dec. 1992		Mar. 1993		June 1993	
4	37.6	370	69.5	404	16.8	449	27.9	811
5	27.9	334	118.0	324	30.8	589	13.2	666
6	58.7	699	95.6	295	31.3	187	54.2	697
7	57.8	702	58.7	582	11.4	151	75.5	300
8	67.5	604	56.5	153	9.2	325	86.1	125
9	15.4	825	20.2	99	14.5	173	35.3	336
10	27.6	948	85.8	470	10.5	236	40.3	360
11	32.6	456	40.3	126	8.5	110	47.7	471
12	20.5	242	15.4	172	15.4	188	12.9	545
Average	38.4	576	62.2	292	16.5	267	43.7	479
	Sept. 1993		Dec. 1993		Mar. 1994		June 1994	
4	10.8	281	8.2	418	49.9	140	27.4	218
5	6.2	183	12.8	130	40.7	147	19.4	488
6	13.7	267	7.2	411	16.8	672	29.9	613
7	10.8	262	7.7	596	15.7	202	26.2	235
8	4.0	370	13.4	302	11.9	402	21.3	733
9	7.9	300	8.9	379	27.7	424	15.4	587
10	7.5	167	8.3	114	13.6	274	16.2	300
11	4.0	91	12.2	101	10.8	324	27.4	412
12	3.5	124	7.9	213	14.0	221	13.2	322
Average	7.6	227	9.6	296	22.3	312	21.8	434
X1	18.2	50	10.0	415	14.2	486	20.6	368
X2	19.3	29	10.3	518	15.1	186	33.1	578
X3	22.8	546	7.2	154	14.5	514	32.3	599
X4	14.2	461	7.4	133	12.0	414	18.9	717
Average	18.6	271	8.7	305	13.9	400	26.3	565

	Sept. 1994		Dec. 1994		Mar. 1995		May 1995	
4	22.5	347	12.6	214	1.4	238	45.9	228
5	14.8	82	30.5	498	1.7	184	101.3	
6	10.6	338	81.0	550	2.8	173	118.1	828
7	25.4	167	54.2	297	1.4	122	191.0	158
8	21.4	381	11.9	92	3.2	253	81.6	201
9	6.0	368	8.9	471	1.1	251	160.2	200
10	7.9	472	14.6	507	1.2	223	95.0	123
11	14.9	363	8.3	526	1.2	212	86.1	229
12	10.5	330	8.5	256	1.7	290	81.9	291
Average	14.9	316	25.6	379	1.7	216	106.8	282
X1	16.0	137	11.1	680	1.2	155	49.7	
X2	20.0	61	14.2	261	0.8	241	49.3	89
X3	24.8	135	15.9	203	0.9	286	63.6	143
X4	21.3	267	13.7	754	1.2	185	56.1	471
Average	20.5	150	13.7	475	1.0	217	54.7	234

*Charting coastal stations, 4–12; Algal culture stations, X1–X4.

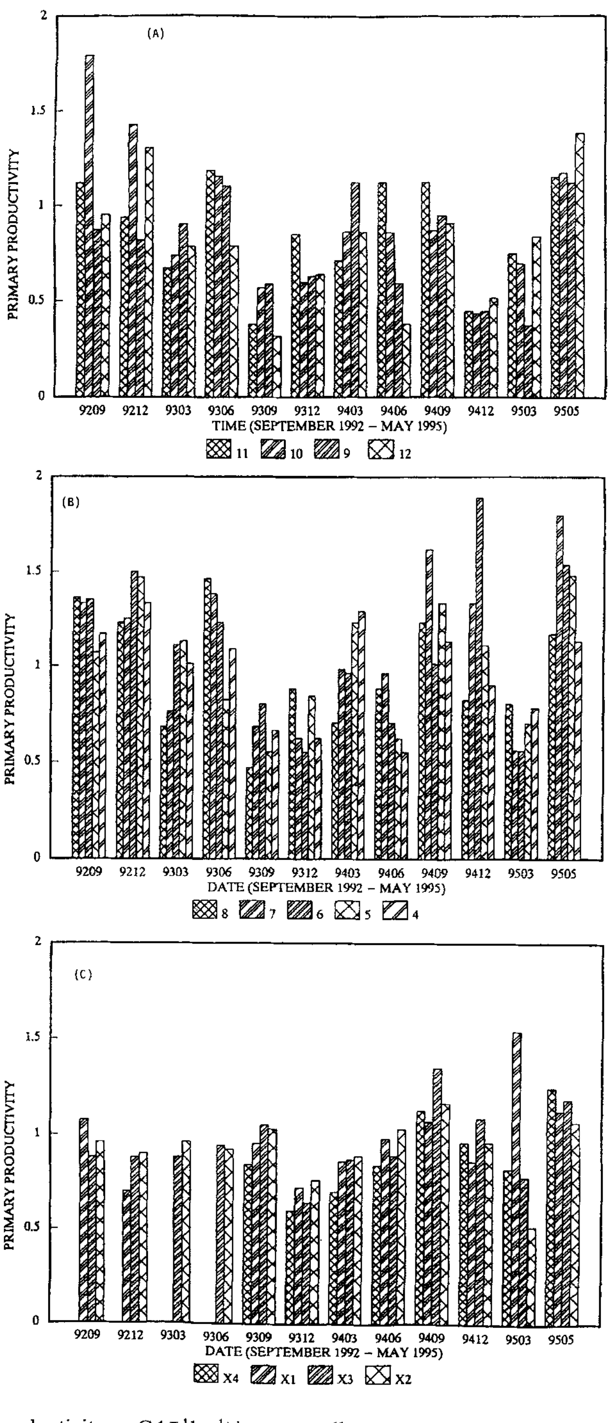


Figure 8 Primary productivity μg C $l^{-1}h^{-1}$) in water collected along the Charting nearshore (Sts. 4–8) and offshore (Sts. 9–12) including the algal cultural (X1–X4) areas (A, Stations 9, 10, 11 and 12; B, Stations 4, 5, 6, 7 and 8; C, Stations X1, X2, X3 and X4).

compared with that found in the period August 1993 to July 1994. The species of phytoplankton present were in the genera *Oscillatoria*, *Nephroselmis*, *Chaetoceros*, *Eucampia*, *Leptocylindrus*, *Thalassiosira*, and *Protoperidinium*.

Analysis of particulate organic carbon (POC) can indicate not only the quantity of phytoplankton but also the organic detritus, i.e. the level of organic pollutants in the water. The POC of organic detritus (POC-d) can be obtained by subtracting POC-p from total POC. In another paper (Hung *et al.*, 1995a) we suggested that higher values of POC (367–21600 $\mu g\ l^{-1}$) were found in river stations compared with those in the Charting coastal waters (49.6–174 $\mu g\ l^{-1}$). Relatively low values (20.6–948 $\mu g\ l^{-1}$) were found in the surface and/or whole water column (0 to 20 m) in the area of algal culture since September 1993. Although the amounts of POC-d at river stations was not analyzed due to the lack of chlorophyll-a data, the distribution of POC-d was similar to that of the total POC on the Charting coastal water, including that of the algal culture area (Hung *et al.*, 1995a). For instance, low POC-d values, 29 to 754 $\mu g\ l^{-1}$ (mean $327 \pm 132\ \mu g\ l^{-1}$) were found in the latter, while at other stations (4 to 12) in the coastal area there were somewhat higher values, 82–948 $\mu g\ l^{-1}$ (mean $339 \pm 103\ \mu g\ l^{-1}$). Furthermore, in the algal culture area, lower values of POC-d ($269 \pm 123\ \mu g\ l^{-1}$) were found in the period from September 1994 to May 1995 and higher values ($385 \pm 114\ \mu g\ l^{-1}$) from September 1993 to June 1994. This evidence supports the view that growth of the algae in an organic polluted area can reduce organic pollutants, as indicated by POC-d.

Primary productivity in Charting coastal water, including the algal culture area, was also measured by carbon-14 uptake. The results (Fig. 8) indicate that primary production ranged from 0.32 to 1.89 $\mu g\ C\ l^{-1}h^{-1}$, varying between season and location. High values were found in May 1995, and lower values in September 1993. Even after the typhoon damage of August 1994, the effect of overall algal growth was still evident. For example, average productivity (0.68 ± 0.06 to $1.23 \pm 0.08\ \mu g\ C\ l^{-1}h^{-1}$) in the algal culture area was higher than that elsewhere in the coastal area (from 0.56 ± 0.14 to $1.13 \pm 0.22\ \mu g\ C\ l^{-1}h^{-1}$) as shown in Table III.

Although the environmental data (salinity, temperature, pH, dissolved oxygen, biochemical oxygen demand and heavy metals) are not presented or discussed here, there are significant correlations between the ecological and environmental parameters in the Charting coastal area. For example, a good correlation (> 0.22) is found between

Table III Comparison of average primary productivity ($\mu g\ C\ l^{-1}h^{-1}$) in the Charting coastal and the algal cultural areas.

Cruise Date	*Charting Coast*	*Algal Culture*
September 1993	0.56 ± 0.14	0.97 ± 0.08
December 1993	0.69 ± 0.12	0.68 ± 0.06
March 1994	0.91 ± 0.20	0.93 ± 0.05
June 1994	0.74 ± 0.22	0.93 ± 0.07
September 1994	1.13 ± 0.22	1.18 ± 0.10
December 1994	0.88 ± 0.47	0.97 ± 0.08
March 1995	0.67 ± 0.14	0.92 ± 0.38
May 1995	1.13 ± 0.22	1.23 ± 0.08

Charting coastal area, 4–12; Algal cultural area, X1–X4.

Table IV Correlation coefficients among the environmental parameters of Erhjin Chi and Charting coastal areas collected from September 1992 to May 1995 (Across, average data, $n = 320$; Down, surface data, $n = 136$).

St.	*Sal*	*Temp*	*pH*	*DO*	*BOD5*	*NO2*	*NO3*	*PO4*	*SiO4*	*Zn*	*Cd*	*Pb*	*Cu*	*CHL.a*	*PP*	*POC*	*ATP*
Sal	1.0000	0.2613**	0.7094**	0.9133**	0.5804**	0.3781**	0.0539	0.6713**	0.8056**	0.5580**	0.3446**	0.4870**	0.4361**	0.2649**	0.4005**	0.8110**	0.6512**
Temp	0.2351**	1.0000	0.1060*	0.1877**	0.2062**	0.1600**	0.0525	0.0209	0.0603	0.0778	0.1137*	0.1250*	0.0492	0.1760**	0.0113	0.1196*	0.0472
pH	0.7383**	0.1179	1.0000	0.7609**	0.3292**	0.5283**	0.0629	0.4489**	0.6449**	0.4228**	0.3740**	0.4402**	0.4745**	0.2072**	0.2768**	0.4411**	0.6108**
DO	0.9145**	0.1653	0.7881**	1.0000	0.5636**	0.4930**	0.0974	0.6810**	0.7967**	0.4828**	0.2188**	0.3592**	0.3890**	0.2458**	0.4071**	0.8021**	0.6364**
BOD5	0.5631**	0.1851*	0.3283**	0.5463**	1.0000	0.2161**	0.3261**	0.5218**	0.4324**	0.2638**	0.0646	0.1558**	0.1074*	0.4620**	0.0904	0.5707**	0.3839**
NO2	0.3714**	0.1733*	0.5426**	0.5060**	0.2079**	1.0000	0.4906**	0.2138**	0.3364**	0.2016**	0.1873**	0.1430**	0.3298**	0.0307	0.0914	0.3362**	0.3659**
NO3	0.0336	0.0729	0.0815	0.0871	0.3069**	0.4796**	1.0000	0.0477	0.0046	0.3670**	0.0766	0.0067	0.1568**	0.0020	0.0963	0.0742	0.1172*
PO4	0.6650**	0.0067	0.4663**	0.6723**	0.5080**	0.2063*	0.0332	1.0000	0.5326**	0.6415**	0.1728**	0.3760**	0.3082**	0.3084**	0.4993**	0.6940**	0.3800**
SiO4	0.7974**	0.0328	0.6667**	0.7933**	0.4129**	0.3309**	0.0149	0.5223**	1.0000	0.3554**	0.1453**	0.2423**	0.2767**	0.2090**	0.3567**	0.7230**	0.7771**
Zn	0.5661**	0.0653	0.4387**	0.4829**	0.2530**	0.1977*	0.0291	0.6390**	0.3490**	1.0000	0.6229**	0.7174**	0.5662**	0.2180**	0.3261**	0.4791**	0.2542**
Cd	0.3459**	0.1112	0.3857**	0.2220**	0.0583	0.1880*	0.0712	0.1721*	0.1440	0.6233**	1.0000	0.9333**	0.6426**	0.1613**	0.1774**	0.1022	0.0630
Pb	0.5043**	0.1460	0.4400**	0.3615**	0.1517	0.1462	0.0101	0.3869**	0.2506**	0.7258**	0.9421**	1.0000	0.6807**	0.2708**	0.2990**	0.2776**	0.1212*
Cu	0.4393**	0.0503	0.4823**	0.3894**	0.0991	0.3340**	0.1529	0.3088**	0.2760**	0.5680**	0.6446**	0.6835**	1.0000	0.2970**	0.3195**	0.3556**	0.3850**
Chl.a	0.2950**	0.2494**	0.1654	0.2277**	0.0328	0.0358	0.0426	0.3306**	0.2276**	0.2258**	0.1610	0.2332**	0.2812**	1.0000	0.7397**	0.2300**	0.1646**
PP	0.4048**	0.0221	0.2341**	0.3885**	0.0727	0.1078	0.0307	0.5113**	0.3599**	0.3250**	0.1712*	0.2738**	0.3037**	0.7139**	1.0000	0.4045**	0.2439**
POC	0.8065**	0.0920	0.4613**	0.7994**	0.5570**	0.3309**	0.0579	0.6885**	0.7152**	0.4758**	0.1017	0.2880**	0.3566**	0.2428**	0.406**	1.0000	0.5689**
ATP	0.6194**	0.1014	0.6307**	0.6055**	0.3517**	0.3613**	0.0880	0.3657**	0.7398**	0.2409**	0.0571	0.1262	0.3943**	0.1896*	0.2515**	0.5373**	1.0000

*$p < 0.05$ **$p < 0.01$

primary productivity and chlorophyll-a, phosphate, POC, salinity, dissolved oxygen, silicate, zinc, copper, lead, ATP and pH; and between chlorophyll-a and BOD, phosphate, copper, dissolved oxygen, silicate, zinc, lead, salinity, temperature and POC, both for the averaged data (all depths, $n = 320$) and for surface water data only ($n = 136$), as shown in Table IV. From these results it may be concluded, in accordance with the observations of Largo and Ohno (1993) and Aziz and Jern (1994) that growing algae in a heavy metal and organic polluted area may clean the water and recreate a healthy ecosystem as well as increase the marine productivity.

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References

Aziz, M. A. and Jern, N. W. (1994) Optimizing algal growth in treating wastewater effluents by activated algae-reactor, In: *Algal Biotechnology in the Asia-Pacific Region*, Eds. Moi, P. S., Borowitzka, M. A. and Whitton, B. A., Proc. of the First Asia-Pacific Conf. on Algal Biotech. 29–31 Jan. 1993, Kuala Lumpur, Malaysia, pp. 285–290.

EPA/ROC (1990) Yearbook of Environmental Statistics in Taiwan area. Statistics Office of Environmental Protection Administration, ROC, pp. 80–131.

Huang, R. (1995) Personal communication.

Hung, T. C. (1988) Heavy metal pollution and marine ecosystem as a case study in Taiwan. In *Hazardous Waste: Detection, Control, Treatment* (Ed. Abbou, R.), Elsevier Science Publ., pp. 869–877.

Hung, T. C. and Meng, P. J. (1992) Species of manganese, iron, lead, chromium and cadmium in the Antarctic Ocean and the Taiwan Erhjin Chi coastal sediments. *Acta Oceanogr. Taiwanica* **28**: 58–68.

Hung, T. C., Han, B. C. and Horng, C. Y. (1989) A case study of green oysters: Dissolved organic matter in the Taiwan coastal water. *Acta Oceanogr. Taiwanica* **24**: 76–95.

Hung, T. C., Meng, P. J. and Han, B. C. (1995b) Interactions among the copper species and forms in sea water/sediments, and copper bioaccumulation in oysters. *Chem. & Ecol.*, **10**: 47–60.

Hung, T. C., Meng, P. J. and Tsai, C. C. H. (1987) Distribution of copper in the Taiwan mariculture area. *J. Chin. Environ. Prot. Soc.*, **10**: 13–34.

Hung, T. C., Han, B. C., Chen, M. H. and Tsai, C. C. H. (1982) Relationships among POC, ATP, chlorophyll-a and primary productivity in the mariculture area of Taiwan western coast. *J. Chin. Agric. Chem. Soc.* **20**: 160–171.

Hung, T. C., Meng, P. J., Wu, S. J. and Chuang, A. (1995a) Restoration of the marine ecological environment along the Charting coastal area: (1) Non-biological environmental study. (in Chem. Ecol. Press).

Largo, D. B. and Ohno, M. (1994) Constructing an artificial seaweed bed, In: *Seaweed Cultivation and Marine Ranching* Eds. Ohno, M. and Critchley, A. T., Japan Intern. Coop. Agency, pp. 113–130.

Raymont, J. E. G. (1980) *Plankton and Productivity in the Oceans*, vol. II Phytoplankton, Pergamon Press, Oxford, 489 pp.

Su, J. C., Hung, T. C. and Chen, J. C. (1986) Ecological and environmental studies along the Erhjin Chi estuary and coastal area. SCOPE/ROC, *Academia Sinica* **43**: 1–35.