# 2000～2001 年粤东柘林湾营养盐分布

周 凯[1], 黄长江[2*], 姜 胜[2], 杜 虹[2], 董巧香[3]

(1. 深圳市海洋与渔业环境监测站, 深圳 518067; 2. 广东省汕头大学海洋生物重点实验室, 汕头 515063; 3. Aquaculture Research Station, Louisiana State University Agricultural Center, Baton Rouge, Louisiana 70803, USA)

**摘要**: 2000 年 5 月～2001 年 5 月对粤东大规模增养殖区柘林湾及湾外附近海域进行了大量营养盐、浮游生物和一般理化因子的周年调查。结果表明, 调查海域溶解性无机氮、磷、硅含量都明显偏高, 年平均值分别达到 22.64、1.95 和 59.7μmol/L。其中, 氮、磷含量均超过国家三类海水的水质标准。由于湾顶黄冈河和湾周边排污排废的影响, 营养盐的分布基本表现为由湾内向湾外, 近岸向离岸递减的格局。大规模增养殖业造成的 2 次污染对该湾营养盐的时空分布具有重要的影响。柘林湾氮、磷、硅含量虽全面偏高, 但如以 Justic 和 Dortch 等的标准来衡量, 该湾浮游植物生长受控于单一营养盐限制因子的出现率为氮 41.75%, 磷 22.9%, 硅 2.36%。

**关键词**: 柘林湾; 营养盐; 分布

# 2000～2001 Annual Dynamics of Nutrients in Zhelin Bay

ZHOU Kai[1], HUANG Chang-Jiang[2*], JIANG Sheng[2], DU Hong[2], DONG Qiao-Xiang[3]

(1. *Oceanic and Fishering Environment Monitoring Station of Shenzhen*, *Shenzhen* 518067, *China*; 2. *Laboratory of Marine Biology*, *Shantou University*, *Shantou* 515063, *China*; 3. *Aquaculture Research Station*, *Louisiana Agricultural Experiment Station*, *Louisiana State University Agricultural Center*, *Baton Rouge*, *Louisiana* 70803, *USA*). ***Acta Ecologica Sinica*, 2002, 22(12): 2116～2124.**

**Abstract**: Zhelin bay is one of the most important estuaries for marine culture in Guangdong Province of China. With the constantly increasing human population and marine culture in the last 10 years, the ecological environment has significantly changed. Although *Phaeocystis* blooms had brought tremendous economic loss and ecological damage in this area in 1997 and 1999, few studies followed and previous investigation of nutrients are very little. To understand why *Phaeocystis* blooms frequently hit this area and how the increased marine culture affects this ecosystem, we investigated the temporal and spatial distribution of phytoplankton, zooplankton, nutrients, trace element, dissolve oxygen, etc. from May 2000. This paper describe the distribution of nutrients in a 1-year period (05/2000～05/2001).

Zhelin Bay (116°E, 23°N) is a land-locked estuary. Its surface area is 68～70km$^2$ and mean depth is 4.8m, and its sediments mainly consist of sandy and sand muddy. Tide in this bay is typical semidiurnal and its mean range is 1.69m with the maximum of 3.06～3.33m.

Water samples were collected from eight stations weekly (March to November) or biweekly (December to February). Sampling was scheduled to cover the period around high tide (±1.5h). At each station, water samples for nutrient analysis were collected from 0.5m below the surface and 0.5m above the bottom and filtered with 0.45μm cellulose filters immediately. Samples were then kept in a cooler and transported to the laboratory for further analysis. The dissolved inorganic nitrate, nitrite, ammonium, phosphate and silicate were analyzed with the SKALAR SAN + 4-Channel Seawater segmented flow nutrient analyzer and SHMADZU UV-2501 PC equipped with routine spectrophotometric methods modified for the analysis of waters of variable salinity. In detail, silicate was analyzed by silico-molybdenum yellow; phosphate was analyzed by phospho-molybdenum blue; nitrate was analyzed by the copper-

基金项目: 广东省重大科技兴海资助项目(A200005F02); 国家教育部骨干教师资助项目[2000(23)号]

收稿日期: 2001-08-31; 修订日期: 2002-03-13

作者简介: 周 凯(1965～), 男, 湖北武汉人, 博士。主要从事海洋浮游植物和海洋生态学研究。

* 通讯作者 Author for correspondence, E-mail: cjhuang@stu.edu.cn

cadmium reduction; nitrite was analyzed by diazo-azo and sodium hypobromite oxidation for ammonia. Water temperature and salinity were measured *in situ* with YSI meter (model 6600). Because Zhelin Bay is shallow and the water is well-mixed, the data were recorded as the average of samples from surface and bottom unless otherwise indicated.

The annual water temperature decreased from 23.6℃ at the inner bay (station 1) to 22.0℃ at the outer bay (station 8). On the contrary, salinity increased from station 1(19.6) to station 8 (29.6). Temporally, water temperature was high in July (27.8℃) and low in January (16.4℃). Salinity was high in November (31.9) and low in July (24.7), which derives from the dilution of monsoon in July.

Nutrients decreased gradually from the inner bay to the outer bay. On average, dissolved inorganic nitrogen (DIN) was high (35.3 μmol/L) at station 1 and low (15μmol/L) at station 8. Silicate decreased gradually from 110.9μmol/L at station 1 to 34.6μmol/L in station 8. Salinity had negative correlations with silicate ($r=-0.6$; $P<0.0001$) and DIN ($r=-0.51$; $P<0.0001$), which suggested that the discharge of freshwater from Huanggang river diluted the salinity while loaded the nutrients in the inner bay. However, the highest dissolved phosphate (2.66μmol/L) was found at station 3, not at station 1 where is the mouth of Huanggang River. This is due to the high turbidity in the mouth area inhibited the transformation of phosphate from particulate to dissolved phase. The phosphate－salinity relationship indicated the non-conservative in Zhelin Bay.

Nutrients also showed significant seasonal changes. The highest DIN (39.18μmol/L) was in April, but dropped to 9.93～14.14μmol/L between July and October with the increasing temperature. The highest phosphate (monthly mean 3.38μmol/L,) was in December, and it decreased to the lowest (monthly mean 0.72μmol/L) in May. But it started to increase from June and reached to 1.54μmol/L in August and 1.94μmol/L in September. Monthly mean showed the lowest silicate (30.95μmol/L) in May, which probably due to the uptake of silicate by the diatom in the spring blooms. But the increasing influx of Huanggang River in monsoon increased the silicate sharply. The monthly averages of silicate were 66.71μmol/L in July and 66.49μmol/L in August. It reached to 71.59μmol/L in December. Generally, phytoplankton blooms in spring and decreases in summer because of the nutrient depletion. In Zhelin Bay, however, the nutrients, especially silicon and phosphate, were still high in summer. Coupling with the high temperature in summer, the abundance of phytoplankton was higher in summer (July～August, ranging from 0.6 to $1.1\times10^{6}$ cells/L) than that in spring (May～June, ranging from 4.6 to $5.6\times10^{5}$ cells/L).

Compared with most estuaries in the world, the annual mean of DIN in Zhelin Bay (22.64μmol/L) was low, whereas the phosphate (1.95μmol/L) and silicate (59.7μmol/L) were very high. Ratios of DIN:P, Si:P and Si:DIN in the water column of Zhelin Bay implied the stoichiometric limitation of 41.7% in N, 22.9% in P and 2.4% in Si. This finding suggested that N limitation might be more prevalent than P and Si in Zhelin Bay, which is different from most other estuaries in China where P and/or Si limitation were predominant. This finding also indicted that this area was more suitable for the occurrence of diatom blooms than that of dinoflagellate.

The low diversity ($H=1.9$) and evenness ($J=0.49$) of phytoplankton in Zhelin Bay have already indicated its changes of community structure brought by the overload of marine culture. Pressures come from aquaculture will continuously affect the phytoplankton community, which in turn may affect the biogeochemical cycles of nutrients as well.

**Key words**: ntrients; dynamics; Zhelin Bay

**文章编号**:1000-0933(2002)12-2116-09　**中图分类号**:Q948.8　**文献标识码**:A

柘林湾是广东省粤东地区 12 个重要海湾之一,其海水增养殖密度位居广东省前列。由于良好的避风条件,从 20 世纪 80 年代末以来,柘林湾海水养殖业发展迅速,养殖规模不断扩大,使得该湾的生态环境发生了巨大变化,并成为赤潮多发区和生态脆弱区。1997 年底和 1999 年 7 月中旬发生的大规模棕囊藻赤潮,曾使该湾的渔业经济及生态环境受到沉重打击[1,2]。本文通过对柘林湾及其湾外附近海域营养盐的周

年调查，旨在从生态学角度分析和评价大规模增养殖渔业和排污排废对该湾构成的生态压力，探讨该湾大规模有害赤潮频发的生态背景，为研究和制定该湾海水增养殖业可持续发展和生态保护策略提供基础的背景资料。

## 1 海域概况及分析方法

### 1.1 调查海域概况

柘林湾位于闽粤两省交界处，东经 116°57′～117°06′，北纬 23°32～23°37′。内湾呈平放的葫芦状，东西轴长，南北窄(图 1)。东西北三面为陆地所包围，湾口朝南，面向南海。北依饶平县黄冈镇，湾顶处有一黄冈河流入该湾，该河全长 88 km，流域面积 1317.5 $km^2$；南有汛洲、西澳两岛相伴；东起柘林港；西至海山岛，相邻三百门港。该湾水域面积宽阔，达 68～70 $km^2$。水底为泥沙，水深 3～12m，平均 4.8m。以汛洲为界，其西部水域深于东部。该湾潮汐为典型的不规则半日潮，平均潮差为 1.69m，月最大潮差达 3.06～3.33m，涨潮历时大于落潮历时，落潮流速大于涨潮流速[3]。

### 1.2 采样与分析方法

调查海区及采样站位布设如图 1。$S_1$ 位于黄冈河口，$S_2$ 站位于养殖面积为 15 $km^2$ 的太平洋牡蛎养殖区中心，$S_4$ 和 $S_6$ 站分别位于养殖规模为 1.7 万格和 1 万格的网箱鱼排增养殖区中心，$S_3$ 站位于牡蛎(0.5 $km^2$)和网箱鱼排增养殖(1.2 万格)的混养海域；$S_5$ 站位于养殖规模为 0.6 万格的网箱鱼排养殖海域。站位定点和养殖面积的测定采用 Garmin 公司生产的 GPS12 型全球卫星定位系统。网箱鱼排规模的计算采用现场计数及抽样平均推测。

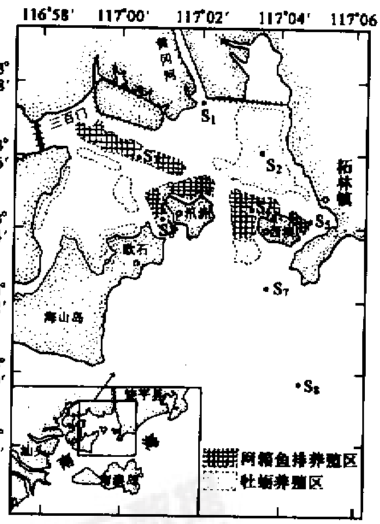


图 1 粤东柘林湾营养盐调查站位的分布

Fig. 1 A map of Zhelin Bay, East Guangdong, showing the sampling stations for nutrient survey

现场调查期间为 2000 年 5 月～2001 年 5 月，冬季每月采集 2 次，其余季节每月 3～4 次，每次采样于高潮前后 1h 内完成。

水样采集分表层(离水面 0.5m)、底(离水底 0.5m)两层。采样装置及容器均用 1∶5HCl 浸泡，然后用蒸馏水冲净。水样采集后，立即经 0.45μm 的 Millipore 滤膜减压过滤后带回实验室，然后用荷兰 SKALAR 水质微量流动注射分析仪和日本岛津 UV-2501 紫外/可见分光光度计进行营养盐等水化指标的测定。其中，硅酸盐($SiO_3$-Si)用硅钼蓝法，磷酸盐($PO_4$-P)用磷钼蓝法，亚硝氮($NO_2$-N)用重氮偶氮法，硝氮($NO_3$-N)用铜-镉还原法，氨氮($NH_4$-N)用次氯酸钠氧化法。现场水温、盐度、溶解氧等用美国 YSI-6600 型水质分析仪测定。

文中引用数值均为表、底层平均值。溶解性总无机氮(DIN)为 $NH_4^+$、$NO_2^-$ 和 $NO_3^-$ 三氮之和。

## 2 结果

### 2.1 水温和盐度

调查海区水温湾内略高于湾外(图 2)。黄冈河口 $S_1$ 站的水温最高(16.2～30.3℃)，年平均值为 23.6℃。湾外 $S_8$ 站最低(15.4～27.1℃)，年平均值为 22.0℃。调查期间柘林湾水温的季节变化比较显著(图 3)，变化范围在 15.4～30.3℃，整个海区的周年平均值为 23.0℃。1 月水温最低，月平均值为 16.4℃。7 月最高，月平均值为 27.9℃。

调查海区盐度由湾内向湾外递增的趋势非常明显(图 2)。黄冈河口 $S_1$ 站的盐度最低(5.1～24.3)，年平均值只有 19.6，而湾外 $S_8$ 站最高(23.6～34.6)，年平均值达 29.6。由于离柘林湾约 10km 处横卧着面积为 108$km^2$ 的南澳岛(图 1)，从而减弱了外海水对该湾的影响，使其盐度明显低于一般外海水的 35。调查期

间盐度的变化范围为 5.1～34.6,整个海区的周年平均值为 26.7。由于受雨季及地表径流的影响,调查海区盐度的季节变化比较明显(图 3)。夏季盐度相对较低,最低的 7 月份平均值为 24.7。秋季较高,最高的 11 月份平均值达到 31.4。

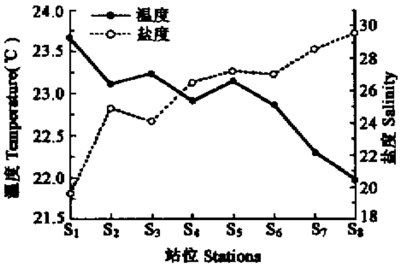


图 2　各调查站位水温和盐度的周年平均值

Fig. 2　Annual averages of water temperature and salinity in each station

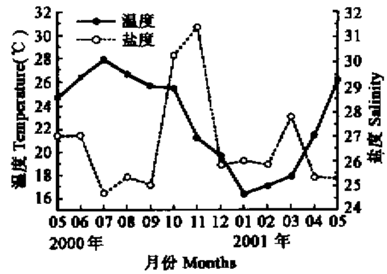


图 3　调查海区水温和盐度月平均值的周年变化

Fig. 3　Annual variation of monthly averages of water temperature and salinity in the investigated area

## 2.2　溶解无机氮

调查海区溶解性总无机氮(DIN)的平面分布特征呈湾内向湾外递减的趋势(图 4)。黄冈河口 $S_1$ 站的含量最高,年平均值为 35.25μmol/L。湾外 $S_8$ 站含量最低,年平均值只有 15.01μmol/L,相差达 1.35 倍。湾内西部海域中央的 $S_3$ 站含量也较高,年平均值为 28.58μmol/L。$NH_4$-N、$NO_2$-N 和 $NO_3$-N 的平面分布特征与 DIN 相似,均以 $S_1$ 站为最高,年平均值分别达到 6.01、2.98 和 26.26μmol/L。湾外 $S_8$ 站含量最低,年平均值分别只有 2.58、1.79 和 10.74μmol/L。

调查期间 DIN 的周年变化范围为 5.43～148.26μmol/L ,整个海区的年平均值为 22.64μmol/L(图 5)。DIN 在春季 4 月份(平均值 39.18μmol/L)达到全年最高峰后逐步下降,于 7 月降至 12.16μmol/L 的低值(平均值),8 月份有所回升,然后再次下降,于秋季 10 月份降到全年最低谷的 9.93μmol/L(平均值)。11 月份又急升至 26.66μmol/L。翌年 1 月份虽略有降低,但幅度较小。

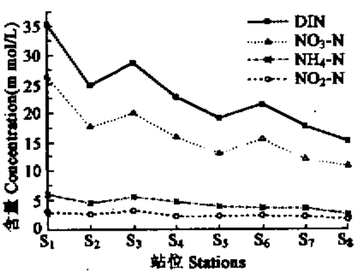


图 4　各站位 DIN、$NH_4$-N、$NO_2$-N 和 $NO_3$-N 的周年平均值

Fig. 4　Annual averages of DIN, $NH_4$-N、$NO_2$-N and $NO_3$-N in each station

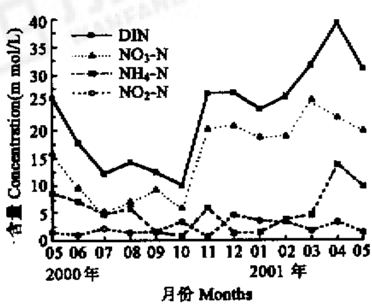


图 5　调查海区 DIN、$NH_4$-N、$NO_2$-N 和 $NO_3$-N 月平均值的周年变化

Fig. 5　Annual variation of monthly averages of DIN、$NH_4$-N、$NO_2$-N and $NO_3$-N in the investigated area

调查期间 $NH_4$-N 含量的变化范围在 0.69～20.62μmol/L,整个海区的周年平均值为 4.34μmol/L(图 5)。$NH_4$-N 含量的高峰值主要位于春、夏两季(4～8 月份)。虽然秋季 11 月有一高值,但整体而言,秋、冬季节的含量明显低于春、夏两季。$NO_2$-N 含量的整体水平较低,高峰期位于冬季(图 5)。调查期间变化范围为

0.65～5.58μmol/L，整个海区的周年平均值为 2.32μmol/L。调查期间 $NO_3$-N 含量的变化范围为 3.53～33.79μmol/L，整个海区的年平均值为 15.22μmol/L，占 DIN 的 70%（图 5）。$NO_3$-N 的周年变动趋势与 DIN 相似，但最大值出现在 3 月（平均值 25.39μmol/L），最低值出现在 7 月份（平均值 5.14μmol/L），而且 8～9 月份的回升比 DIN 略为显著。

## 2.3 溶解磷酸盐

调查海区 $PO_4$-P 平面分布基本表现为从湾内向湾外递减的趋势（图 6），但高值区不在黄冈河口的 $S_1$ 站，而在湾西部中央的 $S_3$ 站（变化范围为 0.43～7.85μmol/L，年平均值 2.66μmol/L）。湾外 $S_8$ 站含量最低，变化范围为 0.14～2.50μmol/L，年平均值 1.58μmol/L。

调查期间 $PO_4$-P 含量的变化范围为 0.14～7.85μmol/L，整个海区的周年平均值达 1.95μmol/L（图 7）。全年最低值位于春季 5 月，6 月明显回升，7 月再次向下，此后一路向上，于冬季 12 月达到全年最高峰的 3.38μmol/L（平均值）。图 7 所示，秋、冬两季（9～2 翌年月份：平均值 2.74μmol/L）形成的高峰非常显著，与春、夏两季（3～8 月份：平均值 1.27μmol/L）构成的低谷形成明显的对比。

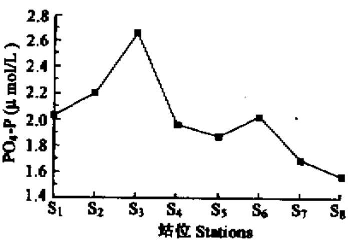


图 6　各站位活性磷酸盐的周年平均值

Fig.6　Annual averages of phosphorus in each station

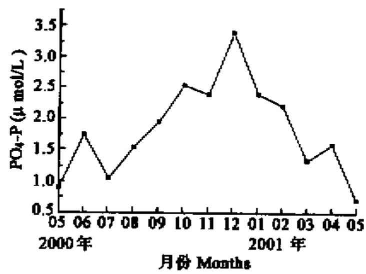


图 7　调查海区活性磷酸盐月平均值的周年变化

Fig. 7　Annual variation of monthly averages of phosphorus in the investigated area

## 2.4 活性硅酸盐

调查海区 $SiO_3$-Si 含量从湾内向湾外递减的趋势非常明显（图 8）。最高值出现在河口 $S_1$ 站（39.21～229.92μmol/L），年平均值为 110.94μmol/L。最低值出现在 $S_8$ 站（8.29～97.47μmol/L），年平均值为 34.58μmol/L，不到 $S_1$ 站的 1/3（图 8）。

调查期间 $SiO_3$-Si 含量的变化范围为 8.29～229.92μmol/L，整个海区的周年平均值为 59.7μmol/L。月平均值的周年变动规律呈比较明显的双峰型（图 9）。最低谷位于春季 5 月，平均值分别为 30.95μmol/L（2000 年）和 34.15μmol/L（2001 年），次低谷位于秋季 9 月份和 10 月份。与 DIN 和 $PO_4$-P 相比，$SiO_3$-Si 含量的夏季（7～8 月份）高峰非常显著，月平均值分别为 66.71 和 66.49μmol/L。

## 2.5 营养盐与盐度的相关性

DIN、$PO_4$-P 、$SiO_3$-Si 与盐度的相关分析表明，调查海区 DIN 和 $SiO_3$-Si 的对数值与盐度存在显著的负相关关系，而 $PO_4$-P 与盐度不存在显著的相关关系。

## 2.6 氮、磷、硅之间的比值

调查海区 N∶P 比值的周年平均值为 11.61，但季节波动极为显著，月平均值变化范围为 3.81～43.04，相差达 11.3 倍（表 1）。N∶P 比值春季（3～5 月份）最高，而秋季（9～10 月份）最低。如表 1 所示，N∶P 比值在 5 月份达到峰值后就逐步下降，于 9 月降至全年最低。Si∶N 和 Si∶P 比值的周年平均值分别为 2.42 和 28.11，季节波动虽也明显，但幅度不到 N∶P 比值的一半，分别只有 5.4 和 4.2 倍（表 1），这主要是调查期间海区 $SiO_3$-Si 含量变动幅度不如 DIN 和 $PO_4$-P 的显著（图 5、图 7、图 9）。Si∶N 比值在 7～10 月（3.98～5.97；平均为 5.18）明显比其余月份（1.10～2.69；平均为 1.99）高。Si∶P 比值的季节波动幅度最小，整体上春、夏两季（3～8 月份）的比值高于秋、冬两季（9～翌年 2 月份）。

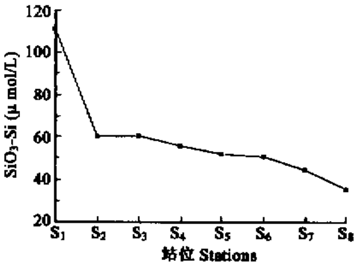


图 8　各站位活性硅酸盐的年平均值

Fig. 8　Annual averages of silicon in each station

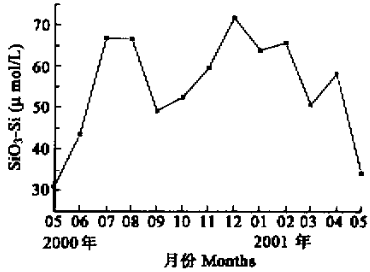


图 9　调查海区活性硅酸盐月平均值的周年变化

Fig. 9　Annual variation of monthly averages of silicon in the investigated area

**表 1　氮、磷、硅之间的比值**

**Table 1　Atomic ratios of dissolved inorganic nitrogen (N), phosphorus (P) and silica (Si)**

| | 日期 Date(年-月 Year-month) | | | | | | | | | | | | | 平均 Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2000 | | | | | | | | 2001 | | | | | |
| | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 1 | 2 | 3 | 4 | 5 | |
| N : P | 28.70 | 10.21 | 11.58 | 7.23 | 3.81 | 3.92 | 11.16 | 7.91 | 12.57 | 8.63 | 23.66 | 24.49 | 43.04 | 11.61 |
| Si : N | 1.20 | 2.45 | 5.49 | 5.97 | 3.98 | 5.27 | 2.23 | 2.68 | 2.69 | 2.52 | 1.60 | 1.48 | 1.10 | 2.42 |
| Si : P | 34.39 | 24.97 | 63.53 | 43.18 | 15.15 | 20.70 | 24.88 | 21.18 | 33.75 | 21.72 | 37.75 | 36.30 | 47.36 | 28.11 |

## 3　讨　论

### 3.1　柘林湾营养盐的分布特征和决定因素

调查结果表明,柘林湾及其附近海域营养盐的分布表现为湾内高于湾外,近岸高于离岸的基本格局,这符合人口密集的半封闭型近岸内湾的特征[4]。DIN 和 $SiO_3$-Si 与盐度的显著负相关关系更说明,由黄冈河和该湾周边排污排废系统入海的工农业废水和城镇居民污水携带的营养盐是柘林湾营养盐的最主要来源。这有力地说明了我国工农业废水和生活污水无法得到有效处理是近岸海域富营养化不断加剧的最根本原因。

图 6 显示 $PO_4$-P 的分布基本上也呈湾内高于湾外、近岸高于离岸的特征,而 $PO_4$-P 与盐度的非线性关系(图 10)应该是黄冈河口附近区域悬浮颗粒较多,对 $PO_4$-P 产生的缓冲作用导致该区 $PO_4$-P 含量相对较低所致[5～7]。黄冈河流域的饶洋、新丰及汤溪等地有许多陶瓷厂、砖瓦厂,大量使用含二氧化硅的粘土,每逢雨季,大量含硅的雨水就随黄冈河一齐入海,既造成了黄冈河口 $S_1$ 站 $SiO_3$-Si 的显著高值,也是柘林湾海水含硅量整体偏高的原因。与氮、磷相比,柘林湾海水中硅酸盐含量在夏天雨季显著上升就源于这些陶瓷厂和砖瓦厂影响(图 9)。

浮游植物数量变动是海区营养盐的另一重要调控因子。调查期间柘林湾浮游植物的数量峰期位于 7～10 月份的高温期,年高峰出现在盛夏 7 月份,而数量低谷出现在晚秋 11 月份至翌年 2 月份[8]。7 月份正值粤东地区雨季[9],入海径流和冲淡水增加,按理,湾内海水中的营养盐含量应相应增加,但实际上除硅酸盐外,调查海区该月氮、磷含量却出现一明显低谷(图 5、图 7)。这显然是海区浮游植物大量繁殖所致。然而,柘林湾浮游植物在 8～10 月份仍处于数量峰期,海区磷含量却从 8 月份开始就一路攀升,直至 12 月份达到全年最高峰。氮含量虽在 10 月份降至全年最低谷的 9.93μmol/L,但与 7 月份的 12.16μmol/L 相差不大,而且 8、9 月份的氮含量仍略高于 7 月份。在夏末秋初的高温季节,柘林湾浮游植物的峰期出现营养盐(特别是磷酸盐)不降反升的现象可能与海区大规模增养殖业的 2 次污染有关。海水增养殖每年投苗一般始于春季,生长旺季位于 5～10 月份,这一期间的投饵量和动物排泄量(包括牡蛎等贝类在内)都值全年峰期,加上高温所致的快速腐败,使海区获得大量的营养盐供应。这一时期的大量营养盐供应可能是柘林湾浮游

植物的年高峰不是出现在春季，而是出现在夏、秋的重要原因。至于这一时期海区磷含量的增加明显多于氮的原因，应该与磷在海区的扩散率明显比氮的低有关[10,11]。

$S_4$、$S_5$ 和 $S_6$ 三个站位都位于湾内近湾口处，其中位处柘林港的 $S_5$ 站明显比其它两站更为封闭，而且柘林镇是个大镇，对 $S_5$ 站产生的生活排污压力也明显比其它两站的大。然而，$S_4$ 和 $S_6$的氮、磷含量却明显比 $S_5$ 的高，这除了归因于 $S_4$ 和 $S_6$ 站的网箱养殖规模（分别为 1.7 万和 1.2 万格）比 $S_5$ 的（0.6 万格）大以外，很难找到其它有力的解释。由此可见，柘林湾海水增养殖业，尤其是网箱养殖业，对海区形成的二次污染是显而易见的。

### 3.2 柘林湾营养程度的现状

调查海区溶解态无机氮、磷、硅的年平均值分别为 22.64、1.95、59.7μmol/L，如果除去湾外 $S_7$ 和 $S_8$ 站，柘林湾溶解无机氮、磷、硅的年平均值分别达到 25.20、2.14、65.12μmol/L，超过了 3 类海水无机氮为 21.42μmol/L（0.3 mg/L），无机磷为 1.45μmol/L（0.045 mg/L）的国家《海水水质标准》（GB3097-1997）[12]。其中，无机磷含量是 3 类海水国家标准的 1.48 倍，可见柘林湾海水富营养化程度已达较高水平。

与磷和硅相比，海洋里氮的来源比较丰富，除了陆地径流和排污排废入海的大量氮源以外，海洋里新增加的氮有 10%～50%可来源于受工业和汽车排气污染的空气[13,14]。因此，随着工业化进程和人类生活水平的提高，海洋里氮含量一直在大量增加[15～17]。由此导致的近岸海域 N：P 和 N：Si 比值的普遍上升，往往使磷和硅成为海域浮游植物生长的限制因子[18～20]。虽然与国内外其它近岸海湾相比（表 2），柘林湾无机氮含

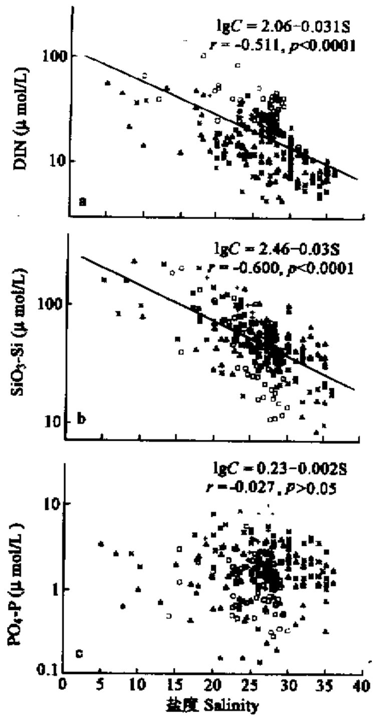


图 10 调查海区 DIN、$PO_4$-P 、$SiO_3$-Si 与盐度的对数回归分析

Fig. 10 A logarithmic analysis between DIN (a), Silicate (b), Phosphate (c) and Salinity in the investigated area (□: 春 spring; ▲: 夏 summer; *: 秋 fall; +: 冬 winter)

表 2 不同海湾溶解无机氮、磷和硅含量之间的比较

Table 2 Comparison of dissolved inorganic nitrogen, phosphorus and silica in different estuaries

| 海湾 Estuaries | 日期 Date | N (μmol/L) | P (μmol/L) | Si (μmol/L) | N：P | Si：N | 参考文献 Reference |
|---|---|---|---|---|---|---|---|
| 柘林湾（湾内）① | 2000-05～2001-05 | 25.20 | 2.14 | 65.12 | 11.8 | 2.58 | 本文 this paper |
| 大连湾② | 1999-01～1999-12 | 85.64 | 0.45 | — | 190.3 | — | [21] |
| 胶州湾③ | 1997-10 | 19.15 | 0.76 | 8.03 | 25.2 | 0.42 | [22] |
| 渤海湾④ | 1998-05～1998-10 | 26.14 | 0.82 | — | 31.88 | — | [23] |
| 同安湾⑤ | 1992-06～1993-04 | 11.36 | 0.38 | — | 29.9 | — | [24] |
| 舟山渔场⑥ | 1996-05～1996-11 | 42.36 | 0.9 | 49.29 | 47.1 | 1.16 | [25] |
| 三门湾⑦ | 1990-02～1990-08 | 17.01 | 0.67 | 32.75 | 25.4 | 1.93 | [26] |
| Tweed | 1991-04～1992-02 | 121.75 | 1.56 | 56.00 | 78.04 | 0.46 | [27] |
| Forth Estuary | 1991-04～1992-02 | 53.25 | 1.21 | 50.51 | 44.01 | 0.95 | [27] |
| Tay Estuary | 1991-04～1992-02 | 50 | 0.69 | 38 | 72.46 | 0.76 | [27] |
| Kuwait Coast | 1994-07～1995-04 | 29.21 | 0.45 | 21.02 | 64.91 | 0.72 | [28] |

① Zhelin Bay(Inner Bay); ②Dalian Bay; ③ Jiaozhou Bay; ④ Bohai Bay; ⑤Tongan Bay; ⑥ Zhoushan Bay; ⑦ Sanmen Bay

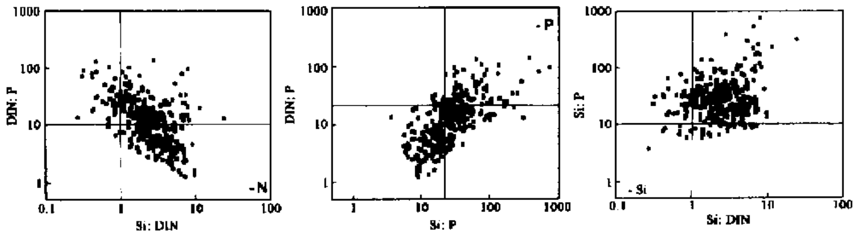


**图 11　调查海区营养盐原子比散点图**

Fig. 11　Scatter diagrams of atomic nutrient ratios in the investigated area (Stoichiometic limitation is indicated by N, P, Si)

量在国内居于中流水平,与国外海湾相比则明显偏低,但是年平均 25.20μmol/L 的无机氮含量已属偏高。相比之下,柘林湾无机磷和硅酸盐的含量则比国内外大多数海湾的高得多。一个海湾同时富含氮、磷、硅的例子并不多见,由此构成的富营养化特征和生态负面效应肯定有其独特的一面。实事上,柘林湾浮游植物群落多样性指数(1.90)和均匀度(0.49)都明显偏低,属于小型硅藻的中肋骨条藻(*Skeletonema costatum*)成为终年优势种,占浮游植物年平均总细胞数的比例竟达 58.7%[8]。像柘林湾这样的生态系必然是一个脆弱的生态系,不具有对大规模赤潮和病害的抵抗能力也在情理之中。

### 3.3　柘林湾浮游植物生长的营养盐限制因子

Justic[19]和 Dortch 等[29]提出:当海水中 Si∶P＞22 和 N∶P＞22 时,磷酸盐为限制因子;DIN∶P＜10 和 Si∶N＞1 时,溶解无机氮为限制因子;若 Si∶P＜10 和 Si∶DIN＜1,则溶解无机硅为限制因子。根据这一原则,将调查海域 Si、N、P 相互之间的原子比作散点图分析(图 11)。结果表明,柘林湾浮游植物生长受控于单一营养盐限制因子的出现率为氮 41.75%,磷 22.9%,硅 2.36%。由此可见,柘林湾浮游植物生长的主要限制因子是氮,而非磷和硅,这与我国许多近岸海域由磷和硅作为主要限制因子的情况差异较大[25,30]。虽然这可能与黄冈河流域发达的陶瓷工业(Si)和该湾的大规模增养殖渔业(P)关系密切,但其生地化循环仍需深入、系统地研究。

## 参考文献


[1] Huang C J(**黄长江**), Dong Q X(**董巧香**), Zheng L(**郑磊**). Taxonomic and ecological studies on a large scale *Phaeocystis pouchetii* bloom in the southeast coast of China during late 1997. *Oceanologia et Limnologia Sinica* (in Chinese)(**海洋与湖沼**), 1999, **30**(6): 581～590.

[2] He J W(**何家菀**), Shi Z X(**施之新**), Zhang Y H (**张银华**), *et al*. Morphological characteristics and toxins of *Phaeocystis cf*. *Pouchetii* (Prymnesiophyceae). *Oceanologia et Limnologia Sinica* (in Chinese)(**海洋与湖沼**), 1999, **30**(2): 172～179.

[3] Cai A Z(**蔡爱智**). The source and environment of sediment in Zhelin bay of Eastern Guangdong province. *Journal of Xiamen University*(in Chinese)(**厦门大学学报**), 1994, **33**(4): 515～520.

[4] Van Bennekon A J and Wetsteijn F J. The winter distribution of nutrients in the Southern Bight of the North Sea (1961～1978) and in the estuaries of the Scheldt and the Rhine/Meuse. *Netherlands J. of Sea Res.*, 1990, **25**: 75～87.

[5] Shengquan G, Guohui Y and Yuhen W. Distributional features and fluxes of dissolved nitrogen, phosphorus and silicon in the Hangzhou Bay. *Mar. Chem.*, 1993, **43**: 65～81.

[6] Ball P W. Nutrient behaviour in two contrasting Scottish estuaries. *Oceanologica Acta*, 1992, **15**: 261～277.

[7] Rendell A R, Horrobin T M, Jickells T D, *et al*. Nutrient cycling in the Great Ouse estuary and its impact on nutrient fluxes to the Wash, England. Estuarine., *Coastal and Shelf Sci.*, 1997, **45**: 653～668.

[8] Zhou K(**周凯**), Huang C J(**黄长江**), Jiang S(**姜胜**), *et al*. 2000～2001 an annual investigation of phytoplankton community in Zhelin Bay. *Acta Ecologica Sinica*(in Chinese)(**生态学报**), 2002,**22**(5):688～698.

[9] Du L M(杜联穆). Investigation of aquatics culture along the east coast of Guangdong province. In Liu J T(刘锦庭)ed. *The exploitation and utilization of ocean resources in Shantou*(in Chinese). Shantou: Science Press, 1998. 268～273.

[10] Froelich P N. Kinetic control of dissolved phosphate in natural rivers and estuaries: a primer on the phosphate buffer mechanism. *Limnol. and Oceanogr.*, 1988, **33**: 649～668.

[11] Windom H L, Byrd J and Smith R, *et al.* Trace metal-nutrient relationships in estuaries *Mar. Chem.*, 1991, **32**: 177～194.

[12] ICS. *Sea water quality standard of Chinese*(in Chinese). (GB3097-1997) 1997.

[13] Prado-Fiedler R. Atmospheric input of inorganic nitrogen species to the Kiel Bight. *Helgol. Wiss. Meeresunters.*, 1990, **44**: 21～30.

[14] Paerl H W. Emerging role of atmospheric nitrogen deposition in coastal eutrophication: Biogeochemical and trophic perspectives. *Can. J. Fish Aquat. Sci.*, 1993, **50**: 2254～2269.

[15] Smayda T. Primary production and the global epidemic of phytoplankton bloom in the sea: a linkage. In: E. M. Cosper, V. M. Bricelj, E. J. Carpenter Eds. *Novel phytoplankton blooms——Coastal and estuarine studies* 35, *Springer-Verlag*, New York, N. Y., USA. 1989. 449～483.

[16] Anonymous. Marine eutrophication. *Ambio*, 1990, **19**:101～176.

[17] Moffat A. Global nitrogen overload problem grows critical. *Science*, 1988, **279**: 988～999.

[18] Justic D, Rabalais N N, Turner R E, *et al.* Changes in nutrient structure of river-dominated coastal waters: stoichiometric nutrient balance and its consequences. *Estuarine*, *Coastal and Shelf Sci.*, 1995, **40**: 339～356.

[19] Justic D, Rabalais N N, Turner R E. Stoichiometric nutrient balance and origin of coastal eutrophication. *Mar. Pollu. Bull.*, 1995, **30**(1): 41～46.

[20] Rabalais N N, Turner R E, Justic D, *et al.* Nutrient Changes in the Mississippi river and system responses on the adjacent continental shelf. *Estuaries*, 1996, **19**(28): 386～407.

[21] Lu Y Y(鲁意扬), Wang Y(王颖), Yin Z M(尹忠民). Study on pollution type and trend of water qualitdy in Dalian inshore. *Marine Science Bulletin* (in Chinese)(海洋通报), 2001, **20**(2): 92～96.

[22] Ren L(任玲), Zhang M P(张曼平), Li T(李铁), *et al.* Distribution of nutrients inside and outside Jiaozhou bay. *Acta Journal of Ocean University of Qingdao*(in Chinese)(青岛海洋大学学报), 1999, **29**(4): 692～698.

[23] Li Q X(李清雪), Tao J H(陶建华). Studies on ecological characteristics of phytoplankton in the waters near Tianjin. *Journal of Tianjin University*(in Chinese)(天津大学学报), 2000, **33**(4): 465～649.

[24] Ji W D(暨卫东), Huang Z Q(黄自强), Huang S G(黄尚高), *et al.* Study on the relationship between eutrophication and red tide in Xiamen harbour. *Acta Oceanologica Sinica*(in Chinese)(海洋学报), 1996, **18**(1): 51～60.

[25] Shi J R(施建荣), Zhang L(张立), Zou W M(邹伟明), *et al.* Distribution feature of the nutrient in seawater of Zhoushan fishery off-shore area. *Marine Environmental Science*(in Chinese)(海洋环境科学), 1999, **18**(2): 43～47.

[26] Zheng X J(郑锡建), Gu F(顾峰), Wu J Y(吴景燕), *et al.* Distribution patterns of hydrochemical factors and interrelationship in waters of Sanmen bay. *Marine Science Bulletin*(in Chinese)(海洋通报), 1993, **12**(1): 30～36.

[27] Balls P W. Nutrient inputs to estuaries from nine Scottish East coast river; Influence of estuarine processes on inputs to the North Sea. Estuarine, *Coastal and Shelf Sci.*, 1994, **39**: 329～352.

[28] Bu-Olayan A H, Al-Hassan R, Thomas B V, *et al.* Impact of trace metals and nutrients levels on phytoplankton from the Kuwait coast. *Environment International*, 2001, **26**: 199～203.

[29] Dortch Q and Whitledge T E. Does nitrogen or silicon limit phytoplankton production in the Mississippi River plume and nearby regions? *Cont. Shelf Res.*, 1992, **12**: 1293～1309.

[30] Zhang J S(张均顺), Shen Z L(沈志良). A study of changes in nutrient structure of Jiaozhou bay. *Oceanologia et limnologia sinica*(in Chinese)(海洋与湖沼), 1997, **28**(5): 529～535.