1996 年德国石荷西部沿岸水域浮游植物种群变动及其整齐圆筛藻赤潮

陆斗定[1], Jeanette Gobel[2], Erik Hagmeier[3]

(1. 国家海洋局第二海洋研究所,国家海洋局海洋动力过程与卫星海洋学重点实验室,杭州 310012; 2. Landesamt für Natur und Umwelt des Landes Schleswig-Holstein, Hamburger Chaussee 25, 24220 Flintbek, Germany; 3. Biologische Anstalt Helgoland Meeresstation, D-27498 Helgoland, Germany)

摘要:1996 年早春至初夏,德国石荷州西海岸水域尤其是在易白河河口附近海区发生了数次赤潮事件,河口区的高叶绿素浓度总是与低盐、高营养盐浓度的分布区吻合。从早春 3 月至 5 月底,发生了持续时间很长的大规模赤潮事件,其引发赤潮原因种为整齐圆筛藻,6 月份对浮游植物生物量的贡献主要来自几种硅藻如微小细柱藻、聚生角毛藻、远洋角毛藻以及属于鞭毛藻类的棕囊藻群体,7 月中旬,自养的纤毛虫类 *Myrionecta rubra*(*Mesodinium rubrum*)达到数量高峰。从 7 月下旬至 8 月中旬,以梭形角藻、叉状角藻占优势的甲藻类几乎贡献了全部的浮游植物生物量,8 月中旬至 9 月上旬为甲藻和硅藻等类别的混合期,9 月中旬以后,硅藻重新占据浮游植物数量的绝对优势,主要优势种为浮动弯角藻、复瓦根管藻等,该海域浮游植物种群的演替反映了温带海域的特征。在早春发生的大规模赤潮期间,整齐圆筛藻的细胞密度达到 2180cells dm^{-3},与之相对应的生物量为 758.1μg C dm^{-3},占浮游植物生物量的 94.2%,整齐圆筛藻的爆发性增殖所产生的大量油膜覆盖了黑尔果兰岛和东 Frisian 群岛周围的海域,这一现象有史以来第一次被卫星所观测到。

关键词:浮游植物种群;赤潮;营养盐;整齐圆筛藻

Phytoplankton population dynamics and *Coscinodiscus concinnus* blooms in the west-coast water of Schleswig-Holstein, Germany in 1996

LU Dou-Ding[1], Jeanette Gobel[2], Erik Hagmeier[3] (1. *Second Institute of Oceanography, SOA, Key Lab. of Ocean Dynamic Process and Satellite Oceanography, SOA, Hangzhou* 310012, *China*; 2. *Landesamt für Natur und Umwelt des Landes Schleswig-Holstein, Hamburger Chaussee* 25, 24220 *Flintbek, Germany*; 3. *Biologische Anstalt Helgoland Meeresstation, D-*27498 *Helgoland, Germany*)

Abstract: Several blooms occurred in spring and throughout the summer near the estuary of the Elbe River, the west coast water of Schleswig-Holstein, in 1996. High Chl a concentration coincide very well with low salinity and total nitrate concentration. From early spring to the end of May, a strong and long lasting bloom, which was dominated by the large diatom *Coscinodiscus concinnus*, occurred in the waters along the west coast of Schleswig-Holstein. In June, several diatoms such as *Leptocylindrus minimus*, *Chaetoceros socialis*, *Cerataulina pelagica*, and colonies of the flagellate *Pheaocystis* contributed to the biomass of phytoplankton. The autotrophic ciliate *Myrionecta rubra* (*Mesodinium rubrum*) reached its highest concentration in

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Brief introduction of author: LU Dou-Ding (1956～), male, Research Assearch Professor. Main study field is ecology of harmful algal blooms.

E-mail: dlu@mail.hz.zj.cn

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July. In the period of July to the middle of August, dinoflagellates were dominant represented by *Ceratium fusus* and *Ceratium furca*. In autumn, diatoms dominated again with species of *Eucampia zodiacus* and *Rhizosolenia imbricata*. The succession pattern of phytoplankton population in this area is a typical one in temperate waters. During the spring blooms, the highest density of *Concinodiscus concinnus* reached 2180 cells dm^{-3} and its peak biomass, which contributed 94.2% of total phytoplankton biomass, was 758.1 μg C dm^{-3} on March 27. The extensive bloom dominated by *Concinodiscus concinnus* in the waters around the island of Helgoland and in the waters along the coast of the East Frisian Islands resulted in producing oily film that covered the surface of the sea. This oil slick produced by this large diatom was first time to be detected by satellite remote sensing in its history.

Key words: phytoplankton population; algal blooms nutrients; *Coscinodiscus concinnus*

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1 INTRODUCTION

Phytoplankton is a group of microscopic unicellular algae that float or swim freely in the sea. They use sunlight energy for the fixation of carbon dioxide in order to produce organic biomass. They are critical food for filter-feeding bivalve shellfish (oysters, nussels, scallops, clams) as well as for the larvae of commercially important crustaceans and fin-fish. In most cases, the proliferation of plankton algae is beneficial for aquaculture, wild fish growth[1] and for marine biomass production. However, for many years and especially in the last a few decades, harmful phytoplankton blooms have had seriously economic impact on the resources of the aquatic fisheries and on public health in many coastal regions of the world. In certain regions algae blooms also had an impact on the tourism. For example, dead fish wash up on shore, layers of smelly foam on beaches or local sea food which is suspected of being inedible. Thus, marine scientists, fishermen and environmental protection agencies of coastal nations are concerned about harmful algal blooms (HABs). Without understanding planktonic algae and its bloom in the sea water, there can be no effective management of the ocean.

Harmful blooms of microalgae can influence the water quality considerably. High cell densities of algae can cause discoloration of the water sometimes combined with a pungent odor of the water. The accumulation of foam caused by *Phaeocystis* can be quite a problem at the coastal zone of European waters. Along the coast of Schleswig-Holstein there is not much fish farming, but tourism plays an important role for the economy in this part of the country. Therefore, the quality of the sea water is extermely important for the tourist industry of this German coastal state[2,3].

The Early Algae Detection System at the State Environmental Agency of Schleswig-Holstein (LANU) was started in 1989. The purpose of the project is to monitor, assess and make short-term predication of the development of microalgae in the coastal waters of Schleswig-Holstein.

This paper presents some basic results of HABs in the west coastal water of Schleswig-Holstein in 1996. The blooms caused by large diatom *Coscinodiscus concinnus* was detected by satellite for the first time in its history and are much concerned by marine scientists and environmentalists.

2 MATERIALS AND METHODS

2.1 Study area

The west coast water of Schleswig-Holstein belongs to the south eastern part of the North Sea. The area includes one of the most important Wadden Sea regions of the world which covers 2500 km^2. The area was declared as National-park in 1985 for protecting and preserving its particular characteristics of the nature. Strong tidal current causes the water well-mixed. The hydrographical condition of the southern part is also strongly influenced by runoff of big rivers, especially the Elbe River. The diversity of phytoplankton population is highly dependent on these environmental factors[4].

The sampling area of the Early Algal Detection System in the North Sea covers an area of 9760 km^2 size (length × width: 80 km×122 km) and has fifteen fixed sampling stations. The location of the sampling stations is more or less to the coastal line. One additional long-term monitoring station is located near the island of Helgoland in the south eastern North Sea (Fig. 1).

2.2 Sampling and data acquisition

A helicopter has been used in taking algal samples at high tide for North Sea area. Therefore, almost synoptic samples could be obtained. The monitoring period is between April and October. The sampling depth 0.5 to 1 m below the water surface using self-made plastic sampler.

Chlorophyll a was measured using a spectrophotometric method with a Perkin Elmer UV/VIS lambda 2 spectrophotometer, according to Jeffrey & Humphrey[5] and Stricland[6]. Phytoplankton cell concentration was quantitied using the Ütermol method[7]. Carbon content was calculated according to Strathmann[8] and Verity[9]. They recommended that the plasma volume be multiplied by a factor of 0.13 for armored dinoflagellates because of the higher carbon content of the their cell wall and 0.11 for all other phytoplankton and ciliates. Nutrient measurement was conducted by the department of Chemistry of the Landesamt für Natur und Umwelt des Landes Schleswig-Holstein. NOAA-AVHRR satellite image was used for detecting sea surface temperature anomalies and large scale algae blooms on cloud-free days.

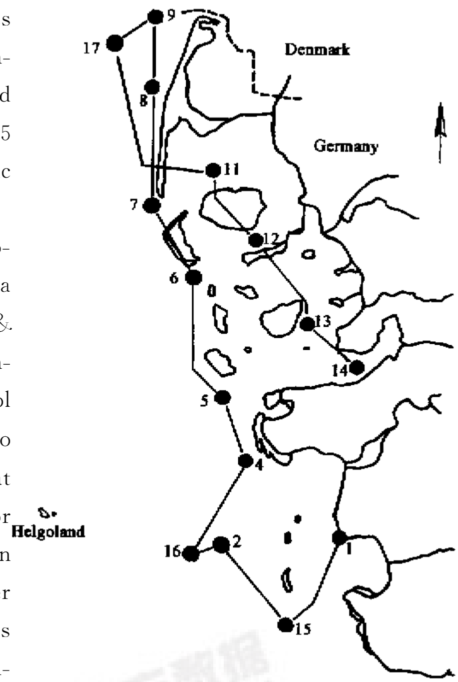

Fig. 1　The location of sampling area

3　RESULTS

3.1 Species composition of potentially harmful species

In the west coast of Schleswig-Holstein, the main causative species of algal blooms are as follows: *Coscinodiscus concinnus*, *Guinardia delicatula*, *Leptocylinedrus danicus*, *Leptocylindrus minimus* are found in more nearshore areas and blooms caused by *Guinardia flaccida*, *Ditylum brightwellii*, *Pseudonitzschia* spp., *Rhizosolenia setigera*, *Rhizosolenia imbricata* are found in the open waters. Blooms of dinoflagellates such as *Ceratium furca*, *Dinophysis* spp, *Gyrodinium* cf. *aureolum*, *Gymnodinium clorophorum* and *Noctiluca scintillans* were usually recorded in more open waters whereas other blooms of dinoflagellates such as *Prorocentrum micans*, *Prorocentrum minimum* and other flagellates like *Phaeocystis globosa*, *Fibrocapsa japonica* and *Heterosigma* are found more nearshore.

3.2 Seasonal and geographical distribution of algal blooms

The results of the monitoring suggest that the development of microalgae blooms is very much dependent on the weather and the hydrographical situation in the coastal waters. By establishing the monitoring programme it is possible to obtain results on the presence of bloom forming species, toxic species and some new recorded species in the area. For instance: the bloom of *Phaeocystis* did not appeared in spring of 1996 as it usually does, because of the long cold winter which depressed the water temperatures in spring and summer time. Furthermore, diatoms were more abundant in 1996 at this time of the year than that in other years. A small toxic flagellate *Fibrocapsa japonica* was detected in the south of Eiderstedt peninsula.

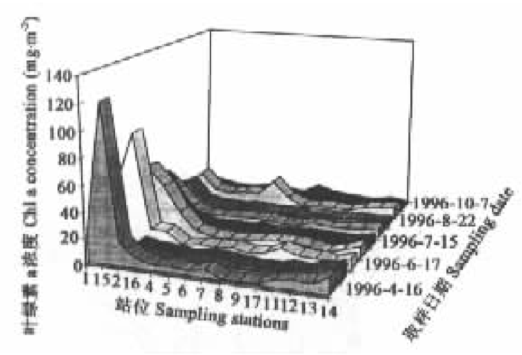

Fig. 2 Distribution of Chl a concentration in the sampling area in 1996

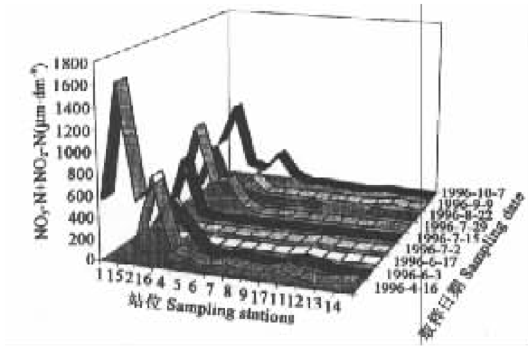

Fig. 3 Total nitrates concentration in the sampling area in 1996

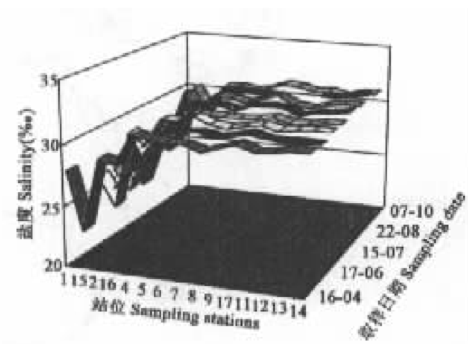

Fig. 4 Salinity in the west coast of Schlesweg-Hostein in 1996

By analyzing composition, time scale, place of origin and spreading direction of algal blooms during sampling season, we found an interesting phenomenon while comparing the results of the northern and the southern part of the monitoring area in the North Sea. The southern area contains usually higher values of phytoplankton biomass than that of northern area. This is mainly due to the influence of the big rivers and the specific hydrographic conditions in that region (Fig. 4). The spatial and seasonal pattern of macro-nutrients (PO_4, NH_4, NO_2, NO_3 and Si) show that high values were detected during spring which may be responsible for the spring blooms. With the development of blooms, the nutrient level decreased during the summer. Macro-nutrient levels rose again after August. Several blooms occurred in spring and throughout the summer at the mouth of the Elbe river in 1996 (Fig. 2). High Chl a concentrations coincide very well with low salinity and high total nitrate concentration (Fig3, 4). Figure 5 clearly shows seasonal variations of phytoplankton biomass of different algal groups at Helgoland Reede. From early spring to the end of May, a strong and long lasting bloom, which was dominated by the large diatom *Coscinodiscus concinnus*, occurred in the waters along the west coast of Schleswig-Holstein. The highest density of *Coscinodiscus concinnus* reached 2180 cells dm^{-3} and its peak biomass, which contributed 94.2% of total phytoplankton biomass, was 758.1 μg C dm^{-3} on March 27. The extensive bloom dominated by *Coscinodiscus concinnus* in the waters around the island of Helgoland and in the waters along the coast of the East Frisian Islands as well as of North frisian Islands resulted in producing oily film that covered the surface of the sea water. This oil slick could be detected by satellite remote sensing. In June, several diatoms such as *Leptocylindrus minimus*, *Chaetoceros socialis*, *Cerataulina pelagica* and colonies of the flagellate *Phaeocystis* contributed to the biomass . The autotrophic ciliate *Myrionecta rubra* (*Mesodinium rubrum*) reached its highest concentration in July. In the period of July to early September, dinoflagellates were dominant represented by *Ceratium fusus* and *Ceratium furca*. In autumn, diatoms dominated again with species of *Eucampia zodiacus* and *Rhizosolenia imbricata*. The succession pattern of phytoplankton population is a typical one in temperate waters.

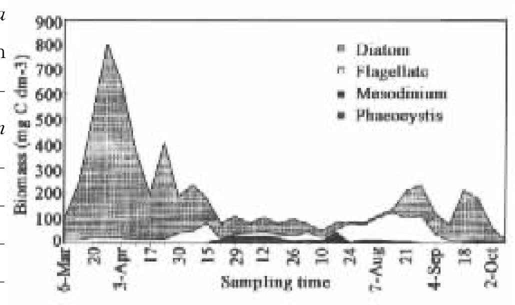

Fig. 5 Phytoplankton biomass at Helgoland Reede in 1996

Higher values of Chl a concentration were always found at the southern stations of the monitoring area especially in the estuary of the Elbe river due to its high mutrient load.

3.3 Detection of algal blooms by satellite remote sensing

Coscinodiscus concinnus is a cosmopolitan species but mainly distributed in the neritic sea water. The diameter of the roundish cells is between 110～500μ. The living cell has mumerous small chloroplasts[10]. It can be sometimes served as host of small heterotrophic flagellate, *Rhynchopus coscinodiscivorus*[11]. Although this species is not toxic, its strong bloom might cause environmental problems. This species together with *Coscinodiscus centralis* were found in the North Sea in very high concentrations, discoloring the water and forming an oily film on the sea surface in May 1947. This sticky oil adhered to birds and resulted in high bird mortality rate[12,13]. This oil slick produced by *Coscinidiscus concinnus* was first time to be detected by satellite remote sensing.

The capability of synoptic recordings of harmuful algal blooms from ocean color detecting satellites was demonstrated. Conclusions were drawn from NOAA-AVHRR sea surface temperature images of the area, together with ground truth information in order to explain the development of the bloom.

4 SUMMARY AND DISCUSSION

There is a strong relationship between algae situation and environmental factors such as salinity, temperature, nutrients and hydrographic conditions. Mary algae species appeared to be stimulated by eutrophication from domestic, industrial and agriculture wastes. The results we have presented in this paper coincided with others: two good examples are Hongkong Harbor[14] and the Seto Inland Sea[15]. The increase of algal bloom shows a striking relationship with the 6-fold increase in human population in Hong Kong and the concurrent 2.5-fold increase in nutrient loading, mainly contributed by untreated domestic and industrial wastes. A similar experience was noted in the Seto Inland Sea, one of the major fish farm areas in Japan. Between 1965 and 1976 the number of confirmed red tide outbreaks progressed 7-fold, concurrent with a 2-fold increase in the COD (Chemical oxygen demand) loading , mainly from untreated sewage and industrial waste from pulp and paper factories. Effluent controls were then initiated to reduce the chemical oxygen demand loading by about half, by introducing secondary sewage treatment and removing phosphates from house-hold detergents. After 4 years of effluent controls, the frequency of red tides in the Seto Inland Sea decreased by about 2-fold to a more stationary level.

The largest regular source of phytoplankton variability is caused by the seasonal cycle of the two main groups: diatom repressenting non-motile cells, and dinoflagellates representing kinetic forms whose swimming ability may be advantageous in stratified water columns. Diatoms show spring bloom and small autumn bloom, while flagellates represented by dinoflagellates produce pronounced summer blooms.

Several algal blooms have been detected by satellite sensors in the North Sea as well as in the Baltic

Sea[16~18]. Filamentous cyanobacteria (blue-green algae) like *Aphanizomenon*, *Nodularia spumigena* and *Anabaena* species) occur usually in higher quantities in the Cental Baltic throughout the summer and early autumn. At the end of their productive phase they accumulate on the sea surface, due to the alterations of gas vesicles which cause cell buoyancy. The accumulation of floating blue-greens on the water surface of the Baltic Sea are easily detected using satellite at a cloud-free weather situation[19], Wind stress can transport the surface drifting blue-green algae accumulation to coastal waters. Some of the filamentous cyanobacteria are toxic or potentially toxic (e. g. : *Anabaena species*, *Nodularia spumigena*). Accumulations of them at the sea surface are characterized with grey-yellowish colour and pungent odor. These factors influence the water quality considerably. Skin irritations of swimmers could result. A general recommendation to the public should be given that especially small children, house pets and other animals do not take a bath in the contaminated water in order to avoid oral uptake of water with high cyanobacteria concentration.

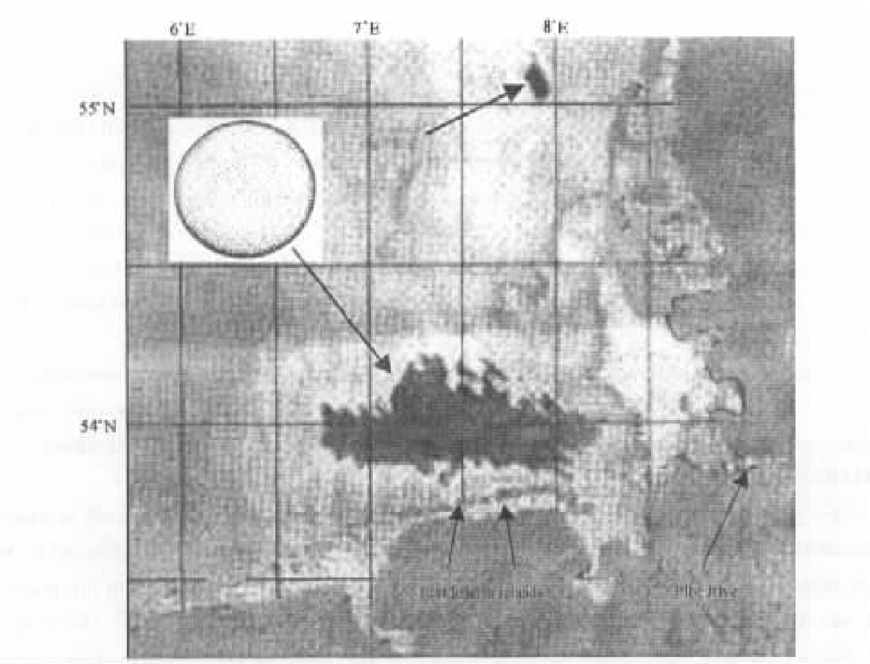

Fig. 6 A satellite picture shows oily film produced by *Coscinodiscus concinnus* (110～500μ in diameter) on the water surface in the German Bight in the spring of 1996

Phytoplankton blooms or near surface accumulations of phytoplankton is frequent in the Chinese coastal waters, the Baltic, the North Sea and their transition areas. In order to establish the early warning system of harmful algal blooms, the combination of remote sensing and the *in situ* monitoing must be considered. Satellite remote sensing of water color in future will be an ideal tool in detecting near surface phytoplankton blooms. More ground truth sampling is necessary to determine the specific characteristics of blooms, including background factors of its occurrence. Characteristic pattern or spatial information has lead to the determination of specific blooms e. g. coccolithophorides or bluegreen algae blooms in the Baltic Sea. More research is needed in order to link different groups or species of algae blooms to be detected from Satellites.

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