



Development of *Phaeocystis globosa* blooms in the upwelling waters of the South Central coast of Viet Nam

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ABSTRACT

Blooms of haptophyte algae in the south central coastal waters of Viet Nam often occur in association with upwelling phenomenon during the southwest (SW) monsoon. Depending on the magnitude of the blooms, damage to aquaculture farms may occur. Based on two years of data on biology, oceanography, and marine chemistry, the present study suggests a conceptual model of the growth of the haptophyte *Phaeocystis globosa*. At the beginning of the bloom, low temperature and abundant nutrient supply, especially nitrate from rain and upwelling, favour bloom development. Diatoms utilize available nitrate and phosphate; subsequently, higher ammonium concentration allows *P. globosa* to grow faster than the diatoms. At the end of the *Phaeocystis* bloom, free cells may become available as food for a heterotrophic dinoflagellate species, *Noctiluca scintillans*. During and after the phytoplankton bloom, remineralization by bacteria reduces dissolved oxygen to a very low concentration at depth, and favors growth of nitrate-reducing bacteria. A Lagrangian Harmful Algal Bloom (HAB) model, driven by a circulation model of the area, realistically simulates the transport of microalgae in surface waters during strong and weak SW monsoon periods, suggesting that it may be a good tool for early warning of HABs in Vietnamese coastal waters.

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1. Introduction

The haptophyte genus *Phaeocystis* has been studied since its description in 1892. There were six species recently re-described with some other suspected new species (Medlin and Zingone, 2007). They are cosmopolitan (Schoemann et al., 2005) and exhibit a complex life cycle and morphology (Whipple et al., 2005; Rousseau et al., 2007). Three species in the genus form colonies and bloom in cold (*P. antarctica*, *P. pouchetii*) and temperate waters (*P. globosa*) (Lancelot et al., 1998). These blooms have impacts on global biogeochemical cycles (Verity et al., 2007) and ecosystem function (Lancelot, 1995; Nejstgaard et al., 2007). Even though *Phaeocystis* spp. have been investigated for almost a century, there is still limited knowledge of their role in coastal ecology and impact on ecosystem function (Whipple et al., 2005; Rousseau et al., 2007). Recently blooms of temperate species *P. globosa* have been observed in subtropical (Lu and Huang, 1999) and tropical waters (Doan-Nhu et al., 2003).

Blooms of *P. globosa* in waters of Binh Thuan Province were recorded in 2002, 2005, 2006, 2007 and 2008 (Doan et al., 2008). These events have been associated with upwelling during the southwest monsoon. In July 2002, about 90% of animal and plant

species in tidal reefs of Phan Ri Bay were destroyed by a bloom, causing a loss of over VND10 billion (ca. \$US 650,000). During this bloom, low diversity of both phytoplankton and zooplankton were reported (Doan et al., 2003). During the blooms in 2005, a few *in situ* data were recorded (Doan et al., 2008), but there are no field data available to describe the bloom in 2006. However, a more extensive investigation in time and space was conducted in 2007–2008 by the Institute of Oceanography Nha Trang. Preliminary results indicate there was a pattern in the development of the bloom, with a change in plankton community composition and nutrient stoichiometry. However, the effects of upwelling activity, nutrient regime, and species competition are complex (Doan et al., 2008). The present paper describes the development of blooms of diatoms, *P. globosa*, and the heterotrophic dinoflagellate *Noctiluca scintillans* and their interaction during the upwelling season in coastal waters of South Central Viet Nam.

Many studies have investigated the conditions which stimulate a bloom of certain phytoplankton species. In Viet Nam, blooms of *N. scintillans* have been reported (Nguyen and Doan, 1996; Nguyen et al., 1997) without any explanation of bloom initiation or demise. This study is an attempt to set up a conceptual model to describe the development and alteration of blooms of diatoms, *N. scintillans*, and *P. globosa* in a tropical, coastal upwelling system in South Central Viet Nam. The latter species drifts onshore and causes significant damage (Doan-Nhu et al., 2003); thus, a Lagrangian HAB model was developed to predict bloom transport as a function of oceanographic conditions.

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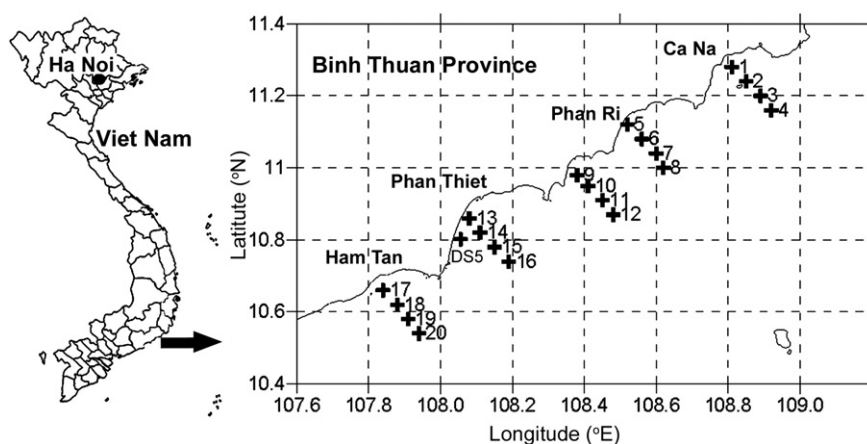


Fig. 1. Map showing sampling location and stations.

2. Material and methods

2.1. The sampling area

The sampling area (Fig. 1) is affected by two periods of prevailing monsoons: southwest (SW) in June–September, and northeast (NE) in October to March. During 2007–2008 the SW monsoon started in May and ended in September. The highest wind speed in 2007 was ca. 10 m s^{-1} for both (Fig. 2).

The rainy season in Binh Thuan Province is from May to October (Fig. 3), and monthly rainfall in 2007–2008 was ca. 200 mm at Phan Thiet station, and two-fold higher in Ham Tan station. Rain during this period was ~80% of the annual rainfall at Phan Thiet, and 90% at Ham Tan. The sampled region was also influenced with fresh-water from two rivers, Ca Ty River in Phan Thiet and Luy River in Phan Ri. Both rivers are small with low discharge (ca. $39 \text{ m}^3 \text{ s}^{-1}$) even during the rainy season. The discharge during dry season is extremely low (Bui et al., 2006).

2.2. Sampling and sample analysis

Samples were taken monthly during 2007–2008; however, in some months sampling could not be done due to rough sea conditions (Table 1). At each station, biological, oceanographic, and environmental parameters were analyzed, including: wind direction and

speed, temperature, salinity, fluorescence, PAR (using a SeaBird CTD 19plus), macronutrients, chlorophyll/pheophytin, total suspended matter, bacterial abundance, phytoplankton composition and abundance, and zooplankton composition and abundance (Fig. 1).

Water samples were taken from a Niskin bottle at the surface, near-bottom and chlorophyll maximum layer. Samples for chlorophyll/pheophytin and nutrients were stored in coolbox with ice. For chlorophyll/pheophytin concentrations, a volume 1–1.5 L of seawater was filtered through GF/F filters (Whatman) on the day of sampling, using a filter rack with 5 filter-holders connected to a vacuum pump (maximal pressure 300 mbar). The filters were wrapped in aluminium foil and kept in a freezer for 2–3 days before extraction. The extraction of phytoplankton pigments was done with storage of individual filter in 5 ml 90% acetol (Merk, Germany) at 5 °C for 24 h. Samples were then centrifuged and absorbance of the supernatant was measured at wavelengths of 630, 647, 664 and 750 nm with a spectrophotometer (HP 8452A). Chlorophyll-a was calculated using the formula of Jeffrey and Humphrey (1975) and pheophytin using the formula of Lorenzen (1967).

For functional bacteria groups, nitrifying (NFB) and nitrate-reducing bacteria (NRB), samples at the surface and near-bottom were immediately inoculated into specific anaerobic media (Widdel and Bak, 1992). Serial dilution culture (three $10\times$ diluted steps) was applied. Cultures were kept in the dark at room temperature for

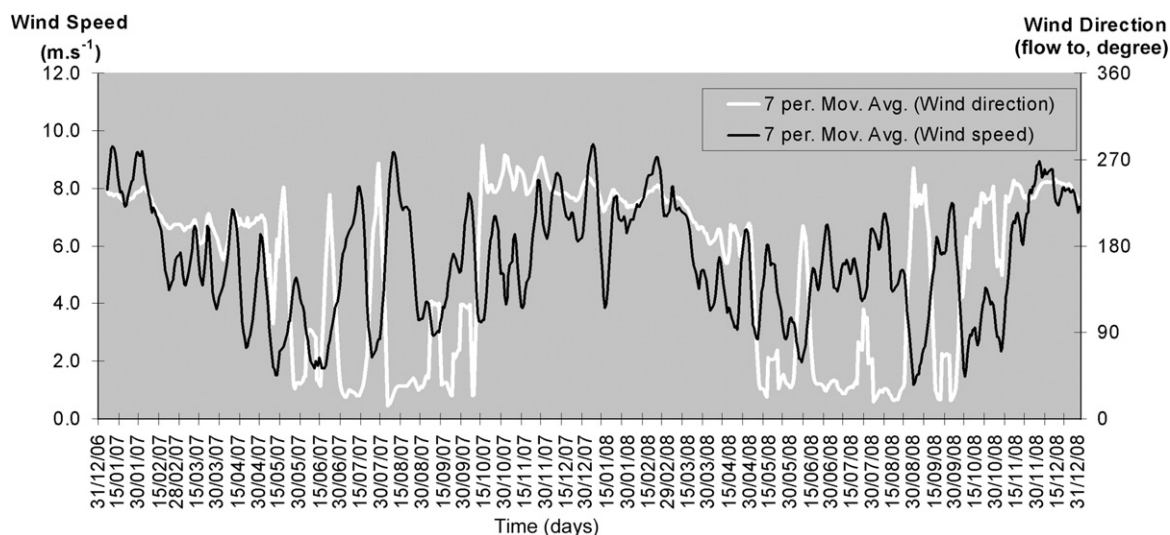


Fig. 2. Monthly precipitation in 2007–2008 at Phan Thiet meteorological station, Binh Thuan Province. (Source: Statistical Yearbook 2008, Binh Thuan Province).

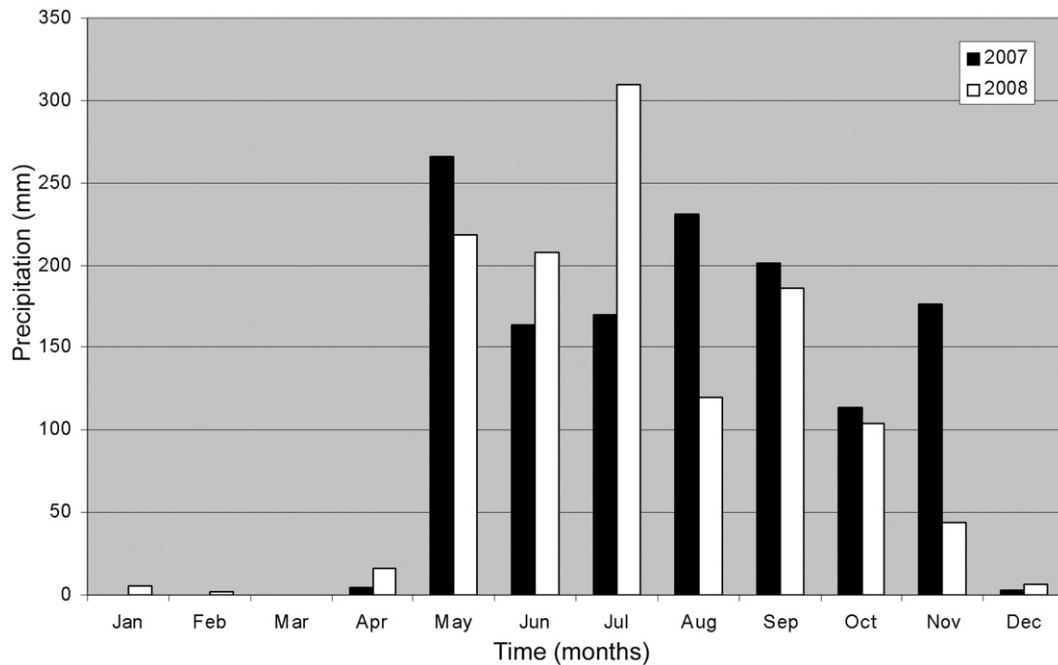


Fig. 3. Daily wind speed and direction at 108.75°E–10.476°N, in 2007–2008, source: <http://iridl.ldeo.columbia.edu>.

2–4 weeks. NFB and NRB bacteria were enumerated using a colorimetric method to check each diluted culture tube for positive (+) and negative (–) calculated by the most probable number method (Widdel and Bak, 1992).

Phytoplankton counts followed Utermöhl method with modification (Larsen and Nguyen, 2004). Carbon biomass of phytoplankton was calculated using cell volume with a minimum of 10 cells for each species (HELCOM, 2007).

2.3. Model description

The numerical model consists of a circulation model in which a Lagrangian HAB model is implemented. The circulation model is a three-dimensional baroclinic tidal model based on the Hamburg Shelf Ocean Model (HAMSOM, Backhaus, 1985). It has a resolution of 4 nautical miles and a time step of 300 s. With this model, six baroclinic surface circulation fields are constructed for strong and weak NE monsoon, strong and weak SW monsoon, and spring and fall inter-monsoon (Hein, 2008). Depending on the intensity of the Southern Oscillation Index (SOI), the velocity fields are linearly interpolated in time and space. These velocity fields drive the Lagrangian HAB model which simulates the transport and diffusion by particle tracking. The transport equation for the Lagrangian particle is

$$\vec{X}_i(x, y, t + \Delta t) = \vec{X}_i(x, y, t) + \Delta t * [\vec{U}_L(x, y, t) + \vec{P}^*(1 - \mu_i) + 0.03 * \vec{W}^*(1 + \lambda_i)]$$

where X_i is the two-dimensional Lagrangian coordinate of the i th particle, U_L is the surface velocity transformed onto Lagrangian

coordinates, P is a bandwidth of turbulent fluctuation, W is the wind speed, and μ_i and λ_i are a random numbers uniformly distributed between zero and unity. The boundary condition is a reflecting boundary condition at the coast. If a particle leaves the model through the open boundary, it is no longer considered in the computation. The particle tracking equation is solved numerically with a fourth-order Runge–Kutta method. To ensure a sufficient accuracy in the model, 5000 particles are considered for the HAB simulation. Details of the numerical procedure can be found in Dippner (2005). Turbulent mixing is assumed to be isotropic, but time-dependent, and is simulated with a Monte Carlo technique. The coordinate X_i of the particle is subject of random displacement. The turbulent fluctuation is assumed to be proportional to the age τ of the individual particle: $P \propto \tau^{0.65}$. This approach is equivalent to the 4/3 power law of diffusion (Okubo, 1971). A detailed description of this technique is given in Dippner (2005). The surface HAB is assumed to be transported with 3% of the actual wind speed. Gusts are simulated as an anisotropic stochastic process in wind direction.

3. Results

3.1. Oceanographic conditions

During the SW monsoon in both 2007 and 2008, distribution of sea surface temperature indicated the development of upwelling, with low temperatures from May to September. The magnitude of upwelling, estimated by area and magnitude of lowered temperatures, varied temporally and spatially (Fig. 4). Variation in upwelling was also observed between years (Fig. 5). 2003 appeared to be warmer, with weaker upwelling.

Table 1

Sampling time and number of visited stations. (9* – an extra sampling trip during bloom of *Phaeocystis globosa*, this sampling including 3 stations at beach in Phan Thiet region and other 3 stations from boat – DS5, 13 and 15).

Year	2007							2008					
Month	5	6	7	8	9*	9	10	4	5	6	7	8	9
No. of stations	20	20	21	24	6	21	14	16	20	16	21	21	17

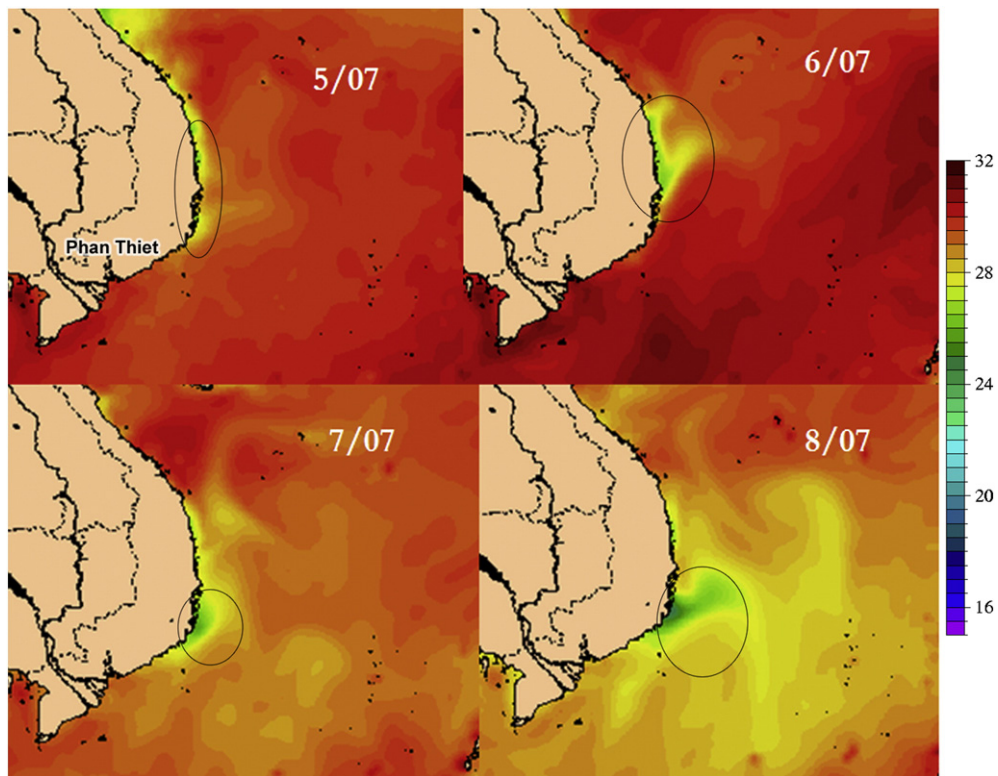


Fig. 4. Sea surface temperature, off Vietnamese coast, in SW monsoon season in 2002–2006. Circles and ellipses show areas with low temperature indicating upwelling. Source: <http://www7320.nrlssc.navy.mil>.

In situ measurements during 2007–2008 indicated upwelling from May to September. The surface (0.5 m) temperature and salinity showed strong upwelling signals in August (Fig. 6). Upwelling was also observed in July 2007 but did not reach the surface.

3.2. Nutrients and dissolved oxygen

Average concentration of nitrate was $2.3 \mu\text{mol L}^{-1}$ in May, reached its maximum of $2.8 \mu\text{mol L}^{-1}$ in July, and decreased to $2.1 \mu\text{mol L}^{-1}$ in

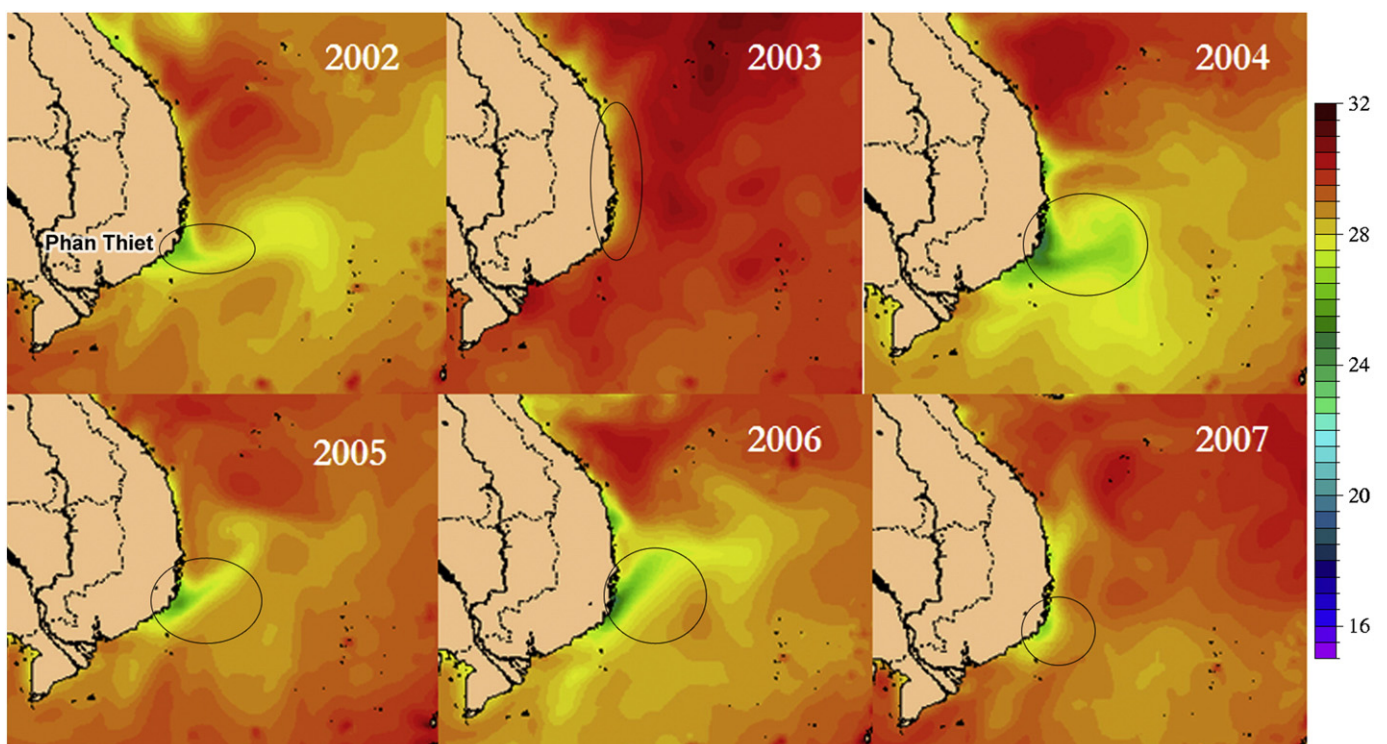


Fig. 5. Sea surface temperature in 2007, in off Vietnamese coast. Circles and ellipses show areas with low temperature indicating upwelling. Source: <http://www7320.nrlssc.navy.mil>.

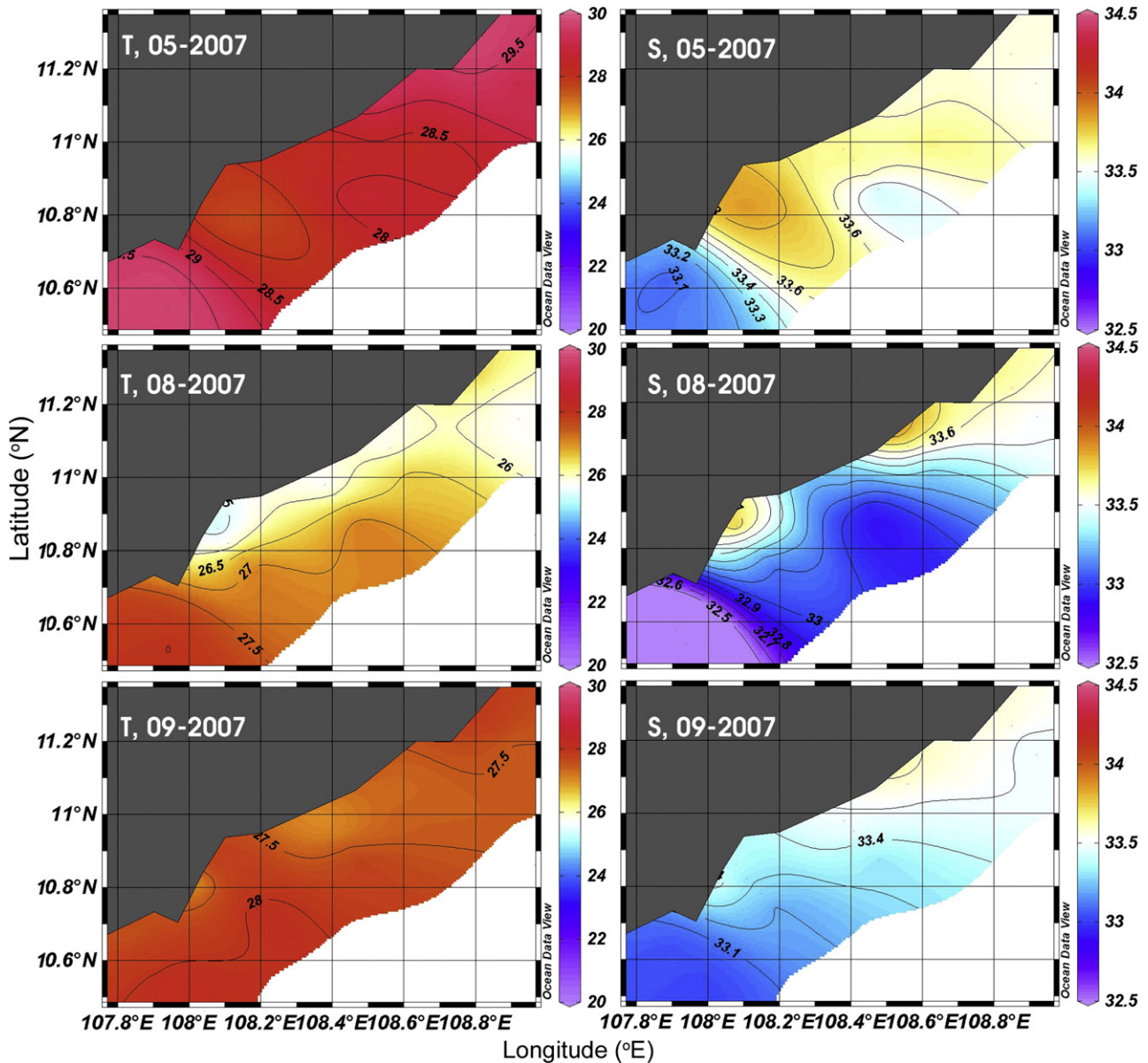


Fig. 6. In situ temperature (left column) and salinity (right column) in May, August and September 2007.

October 2007. Upwelling during May–September thus could have fuelled surface waters with nutrients from deep water. Another source of nutrients during this time could have been fresh-water runoff, since this study was during the rainy season. However, due to low discharge from rivers (Bui et al., 2006), nutrient loading was low. Ammonium concentration ranged from 0.06 to 0.6 $\mu\text{mol L}^{-1}$ in May–August, and were as high as 4.9 $\mu\text{mol L}^{-1}$ in September. Dissolved oxygen (DO) ranged from 5.7 to 6.4 mg L^{-1} in May–August and October, but was as low as 2.7 mg L^{-1} at some stations in September.

3.3. Phytoplankton pigments

Chlorophyll-*a* concentration varied throughout the investigation. Highest chl-*a* concentration occurred during August–September at the nearshore station (37.8 $\mu\text{g L}^{-1}$), with pheophytin of 9.34 $\mu\text{g L}^{-1}$. In September 2007, chl-*a* was highest near the bottom with 18.1 $\mu\text{g L}^{-1}$ and pheophytin 9.81 $\mu\text{g L}^{-1}$. During May–June average chl-*a* was 0.65 $\mu\text{g L}^{-1}$. During the peak of the bloom, chl-*a* reached 336 $\mu\text{g L}^{-1}$ and pheophytin 96 $\mu\text{g L}^{-1}$, at the shore stations where *Phaeocystis* was most abundant.

3.4. Bacteria

The dominance of bacteria alternated among different groups. During periods of low phytoplankton biomass (May–June), nitrifying bacteria (NB) was dominant compared to denitrifying bacteria (DNB), with average of 433 and 81 cells mL^{-1} , respectively. In July to September 2007, the average DNB abundance was extremely high, especially in September 2007, when it reached 2254 cells mL^{-1} , while NB decreased to 20 cells mL^{-1} .

3.5. Phytoplankton biomass and composition

Observations during the SW monsoon showed a clear pattern of development in phytoplankton biomass and dominant species along with upwelling activity. Diatom biomass increased from ca. 20.1 $\mu\text{g C L}^{-1}$ in May–June to ca 35.2 $\mu\text{g C L}^{-1}$ in July–August 2007 and decreased to 12.0 $\mu\text{g C L}^{-1}$ in September–October 2007. A similar pattern occurred in 2008, but with a smaller decrease of diatoms biomass in September (Fig. 7A). In 2007 *P. globosa* formed a bloom at the end of August and the beginning of September (Fig. 7B). Densities

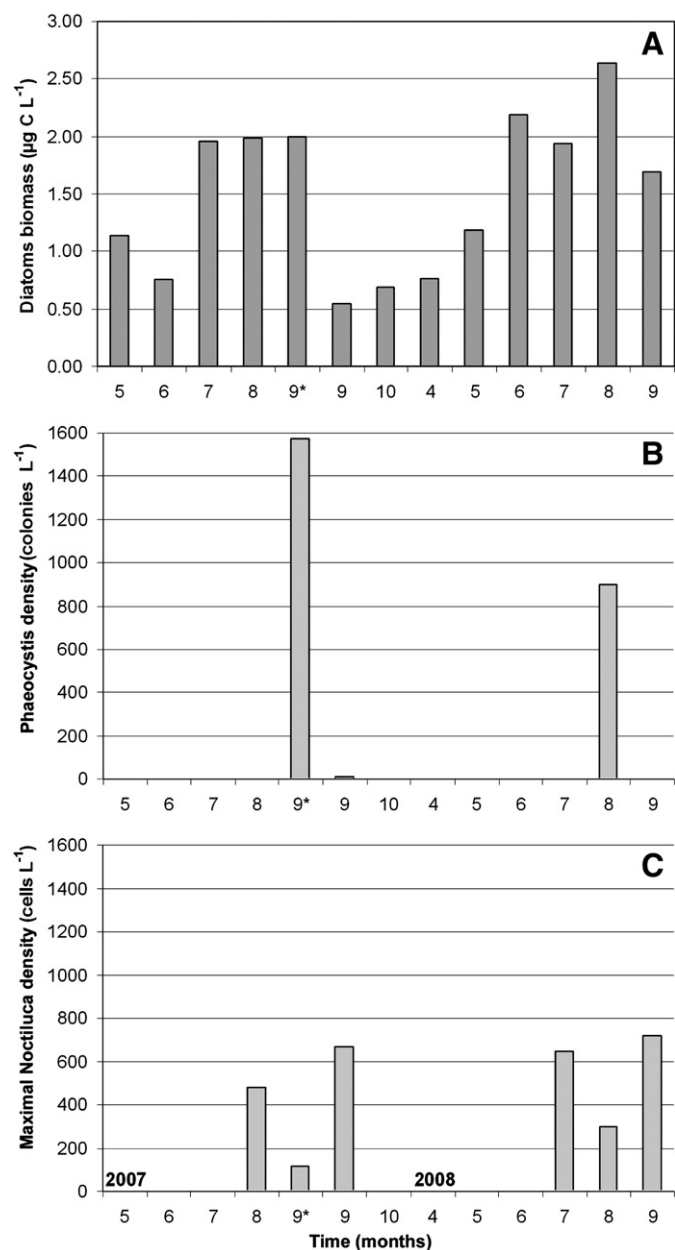


Fig. 7. Variation in A. diatoms biomass ($\mu\text{g C L}^{-1}$), B. *Phaeocystis globosa* colony density (colonies L^{-1}) and C. maximal density of *Noctiluca scintillans* (cells L^{-1}) in 2007–2008. 9*, indicates sampling on 6–7 September during a heavy bloom of *P. globosa* when the number of sampling stations was fewer.

onshore ranged from 1800 to 2200 colonies L^{-1} , decreased to 1000 and 800 colonies L^{-1} at 1 and 3 km offshore, respectively. On 6 September, *P. globosa* was approaching the late stage of a bloom, with some 40% of the colonies being “old”, and estimated biomass from single cell counts was $300.1 \mu\text{g C L}^{-1}$ ($85.2\text{--}694.1 \mu\text{g C L}^{-1}$) at the centre stations of the bloom. At offshore stations, colonies were degrading in the bottom layers. The number of colonies found in the bottom sample was around 10 L^{-1} at station DS5 (close to shore). In 2008 a bloom of *P. globosa* was also recorded in August, but with lower densities of colonies than in 2007 (900 colonies L^{-1}).

Noctiluca scintillans (green type) also formed blooms during our investigation. They reached high numbers after blooms of diatoms in July–August. The highest cell densities recorded in September 2007 and 2008 were 660 and 720 cells L^{-1} , respectively (Fig. 7C). *N. scintillans* and *P. globosa* tended to vary inversely with each other.

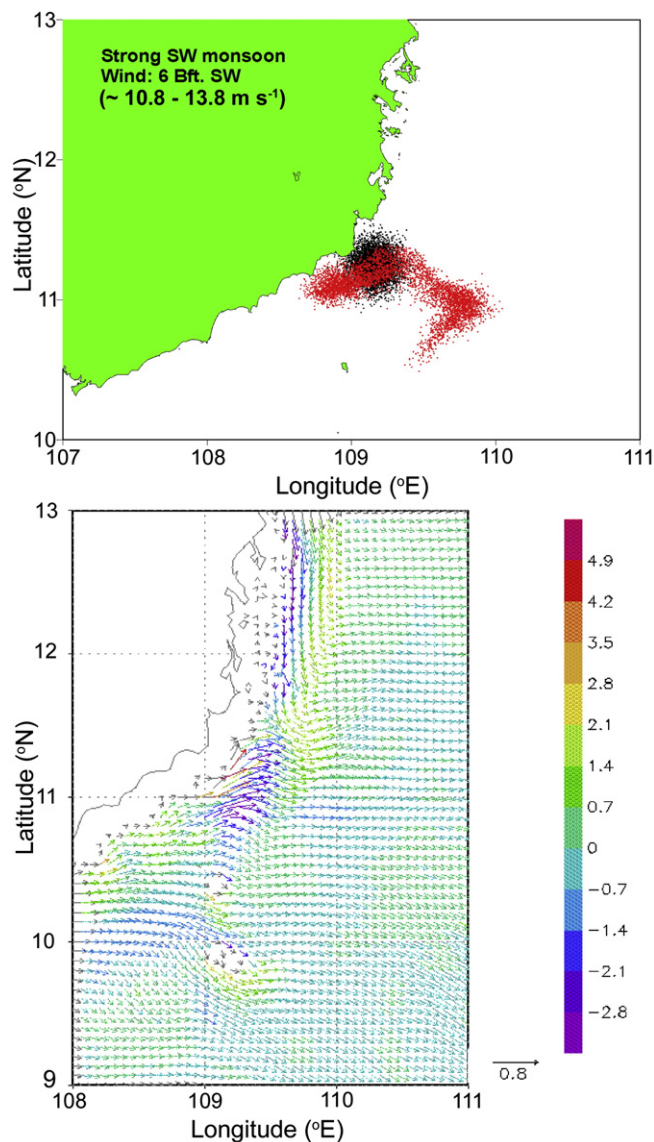


Fig. 8. Simulation of development of a surface bloom of microalgae (initial location at 11.2°N and 109.2°E , diameter 10 km, black/dark dots) in a strong SW monsoon with 6 Bft ($10.8\text{--}13.8 \text{ m s}^{-1}$) wind from the SW. In this case the Ekman transport advects the patch (red/gray dots) offshore (A), and the corresponding surface velocity field (B). The color scale in the velocity field marks the relative vorticity times 10^{-5} .

3.6. Model simulations of bloom transport

Two simulations were conducted to evaluate the impact of wind forcing on bloom transport. In both simulations the initial conditions were the same: a patch of a size of 10 km located at 11.2°N and 109.2°E . The patch was initialized with a Gaussian distribution with an e-folding scale of 10 km. The first simulation was forced with a strong SW monsoon circulation field with 6 Bft. wind ($10.8\text{--}13.8 \text{ m s}^{-1}$) from the SW. In this case, the Ekman transport advected the patch offshore (Fig. 8). The second simulation was forced with a weak SW monsoon circulation field and no additional wind. In this case, no offshore Ekman transport occurred, and the patch was transported parallel to the coast with the coastal jet (Fig. 9).

3.7. Conceptual model

Based on result of present study and previous publications, scenarios of bloom development of the haptophyte *P. globosa* is proposed, along with its interaction with biological and

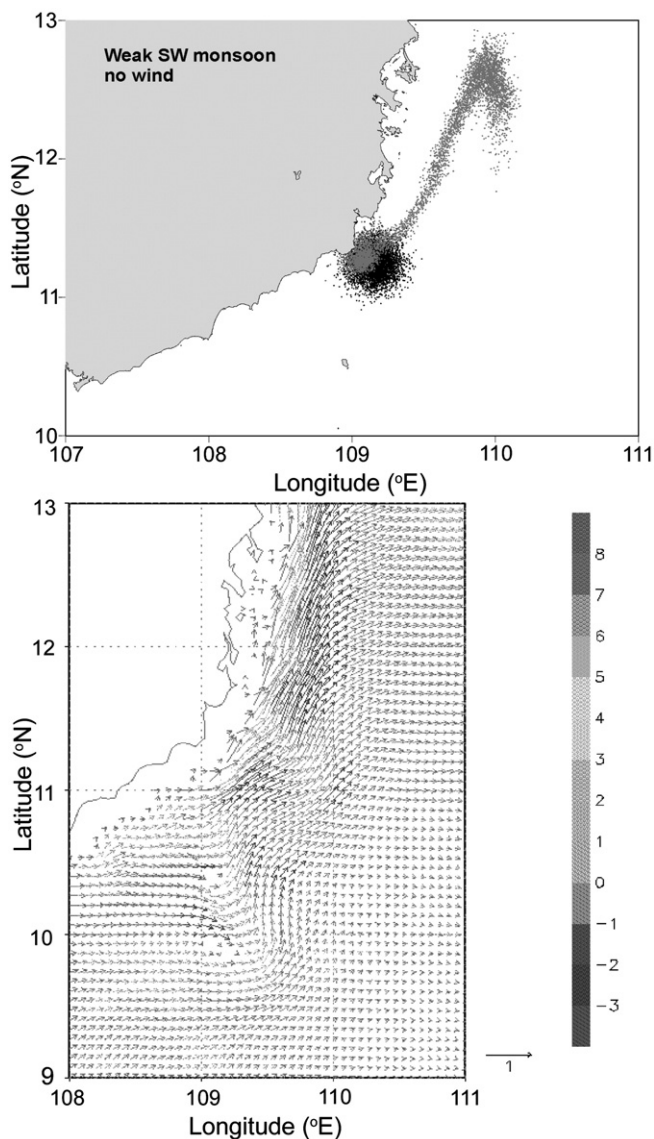


Fig. 9. Simulation of development of a surface bloom of microalgae (initial location at 11.2°N and 109.2°E, diameter 10 km, black/dark dots) in a weak SW monsoon with no wind. In this case no Ekman offshore transport occurs and the patch is transported parallel to the coast (red/gray dots) with the coastal jet (A), and the corresponding surface velocity field (B). The color scale in the velocity field marks the relative vorticity times 10^{-5} .

oceanographic conditions (Fig. 10). Macronutrients (nitrate and phosphate) impact the growth and structure of phytoplankton communities. In May to September, upwelling and rainfall supplied nutrients for phytoplankton growth, so these nutrients concentrations only changed slightly over time. Phosphate may be one of the factors that stimulated growth of phytoplankton in South Central Viet Nam waters.

Turbulence impacts biological responses via increased mixing due to SW wind. The blooms of *P. globosa* occurred in periods with low SW wind speed (ca. $2\text{--}4\text{ m s}^{-1}$). With the rather fragile colonies of the species, this suggests that relatively low turbulence could favour their growth. The blooms of *N. scintillans* occur either before or after the blooms of *Phaeocystis*, and larger numbers are usually found during stronger SW wind conditions (ca. $4\text{--}6\text{ m s}^{-1}$). The more robust cells of this species (compared to *Phaeocystis* colonies) may allow them to better withstand with the turbulence and survive during active mixing conditions.

Bacterial growth responds to increased levels of phytoplankton carbon. At early stages of upwelling, nitrate from upwelling and water runoff were important for nitrifying bacteria. This was associated with the high biomass of NB during May–June. Oxidation processes at the end of the diatom bloom (July–August) reduced dissolved oxygen and favoured growth of denitrifying bacteria.

Diatoms are strong competitors for nutrients, especially when nitrate is available and no silicate limitation occurs. During our investigations high concentrations of silicate were observed ($252 \pm 108\text{ }\mu\text{g L}^{-1}$). Degradation of high phytoplankton biomass, which resulted in high ammonium concentrations, may be unfavourable for diatoms, and hence *P. globosa* and *N. scintillans* in turn become dominant.

4. Discussion

Although the sampling periods were during the SW monsoon periods with some part during the spring inter-monsoon, in general, phytoplankton biomass reveals a clear pattern over the year. Highest biomass occurred during the peak of the SW monsoon upwelling. In 1999, there was a very similar pattern compared to our earlier observation of yearly variations of diatom biomass. The biomass reached nearly $50\text{ }\mu\text{C L}^{-1}$ at the beginning of the upwelling season (SW monsoon) in June–July, and a bloom of dinoflagellates was observed in mid-September, with biomass equal to that of diatoms (Nguyen et al., 2004; Doan-Nhu unpublished data). However, this investigation in 1999 was only in Ca Na Bay, which is at northern transect of our study area (Fig. 1: station 1). Hence the conclusions from this previous investigation were spatially limited.

During 1998–2001, when our sampling took place at different times of the year, we found that biomass during the NE monsoon periods was 2–6 fold lower than those obtained during the SW monsoon periods (Doan and Nguyen-Ngoc, 2008). Daily satellite images (<http://oceanscolor.gsfc.nasa.gov>) for these periods indicate blooms during NE monsoon in quite narrow bands close to the shoreline (images not shown).

During the blooms in 2007 and 2008, phytoplankton decayed near the sea floor, leading to remineralisation by bacteria. Reduced dissolved oxygen favoured the growth of nitrate-reducing bacteria. Ammonium concentration increased by this time. Both ammonium and bacterial biomass may be essential for triggering either *Phaeocystis* or *Noctiluca* blooms. However, a combination of additional factors may be involved in this progression. Our results suggest that the magnitude of turbulence (mixing condition due to SW wind) would be one of the main factors that favour the bloom of either *Phaeocystis* (low turbulence) or *Noctiluca* (moderate turbulence). One biological factor that may be important is grazing, which was not analyzed in this study. The blooms of *Phaeocystis* and/or *Noctiluca* in tropical settings is unusual based on the suggestion that blooms of *Phaeocystis* colonies are restricted to colder waters of polar and temperate systems (e.g. Lancelot et al., 2005; Verity et al., 2007).

Whipple et al. (2005) presented a conceptual model of *Phaeocystis* which considered variation of physical factors (water temperature, light, advection, turbulence, and sedimentation), chemical (dissolved nutrients, inorganic and organic (N), and chemical signals), and biological factors (DNA, genetic mechanisms, grazing, seed particles, viral infection, viral lysis, and non-viral lysis (NVL)) on the life cycle of *Phaeocystis*. In this study, interaction among biological factors has been considered by means of *in situ* measurements in an upwelling system, leading to a new conceptual model. In analyzing this conceptual model, we could not check whether turbulence would stimulate *Phaeocystis* blooms from its benthic stage, or if benthic resting “cysts” were formed. Understanding benthic–pelagic coupling may be of importance to an accurate prediction of these blooms in the future, similar to dinoflagellate HAB blooms of other systems (e.g., Anderson et al., 2005).

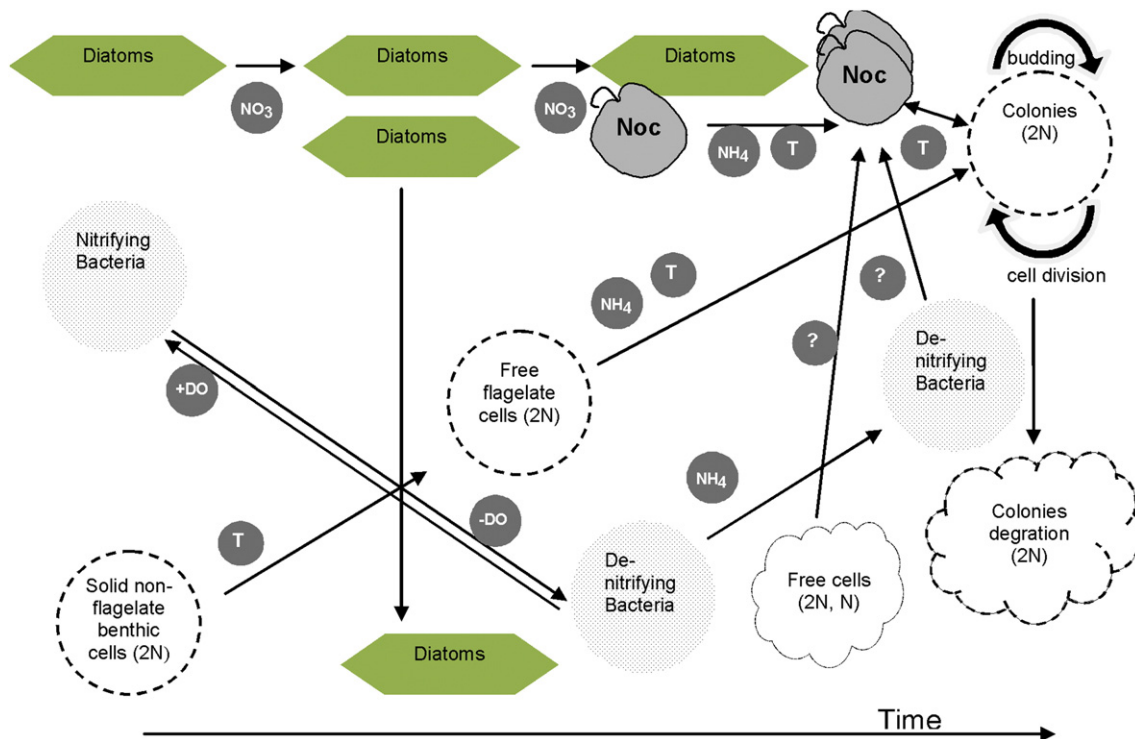


Fig. 10. Conceptual model of development of diatom and flagellate blooms (*Phaeocystis globosa* and *Noctiluca scintillans*) in Binh Thuan Province, Viet Nam, during the SW monsoon season. Notes: Dashed circle/irregular shapes – *Phaeocystis globosa* at different stages of life cycle; Noc – *Noctiluca scintillans*; T – temperature; DO – dissolved oxygen; + and – indicate tendencies toward higher and lower concentrations.

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References

- Anderson, D.M., Stock, C.A., Keafer, B.A., Bronzino, Nelson A., Thompson, B., McGillicuddy, D.J., Keller, M., Matrai, P.A., Martin, J., 2005. *Alexandrium fundyense* cyst dynamics in the Gulf of Maine. *Deep-Sea Res. II* 52 (19–21), 2522–2542.
- Backhaus, J.O., 1985. A three-dimensional model for the simulation of shelf sea dynamics. *Dt. hydrogr. Z.* 38, 165–187.
- Bui, H.V., Ho, V.B., Pham, V.T., 2006. Hydrochemical characteristics and quality of coastal waters in Binh Thuan Province. *J. Geol. A* 297, 38–50 (in Vietnamese with English abstract).
- Dippner, J.W., 2005. Mathematical modelling of the transport of pollution in the water. In: Filar, J.A. (Ed.), *Encyclopedia of Life Support System (EOLSS)* developed under the auspices of the UNESCO. : Mathematical Models. EOLSS Publisher, Oxford UK.
- Doan, N.H., Nguyen-Ngoc, L., 2008. Phytoplankton in Binh Thuan coastal waters in 1998–2001. *Proceedings of Scientific Conference “BIEN DONG – 2007”*, pp. 221–236. Vietnamese with English abstract.
- Doan, N.H., Nguyen, N.L., Nguyen, T.M.-A., Ho, V.T., Nguyen, N.T.G., 2008. Red tides in South Central coast of Viet Nam: biodiversity and planktonic community structure consequences. Poster Presentation at XIII HAB Conference, Hong Kong, November 2008.
- Doan-Nhu, H., Nguyen-Ngoc, L., Nguyen, C., Ho-Van, T., Nguyen-Thi, M.A., 2003. Plankton assemblages during the late bloom of Haptophyte Algae in Binh Thuan province, Southern Central Viet Nam, in July 2002. *Collection of Marine Research Works*, XIII, pp. 105–118.
- Hein, H., 2008. Viet Nam upwelling – analysis of the upwelling and related processes in the coastal area off South Viet Nam. Ph.D. Thesis, University Hamburg, 163 pp.
- HELCOM, 2007. Manual for Marine Monitoring in the COMBINE Programme of HELCOM. Part C. Programme for monitoring of eutrophication and its effects. <http://www.helcom.fi/groups/monas/CombineManual/AnnexesC2007>.
- Jeffrey, S.W., Humphrey, G.F., 1975. New spectrophotometric equations for determining chlorophylls a, b, c1 and c2 in higher plants, algae and natural phytoplankton. *Biochem. Physiol. Pflanzen* 167, 191–194.
- Lancelot, C., 1995. The mucilage phenomenon in the continental coastal waters of the North Sea. *Sci. Total Environ.* 165, 83–112.
- Lancelot, C., Keller, M., Rousseau, V., Smith Jr., W.O., Mathot, S., 1998. Autoecology of the marine haptophyte *Phaeocystis* sp. In: Anderson, D.A., Cembella, A.M., Hallegraeff, G. (Eds.), *NATO Advanced Workshop on the Physiological Ecology of Harmful Algal Blooms: NATO-ASI Series, Series G. Ecological Science*, vol. 41, pp. 209–224.
- Lancelot, C., Spitz, Y., Gypens, N., Ruddick, K., Becquevort, S., Rousseau, V., Lacroix, G., Billen, G., 2005. Modelling diatom and *Phaeocystis* blooms and nutrient cycles in the Southern Bight of the North Sea: the MIRO model. *Mar. Ecol. Prog. Ser.* 289, 63–78.
- Larsen, J., Nguyen, N.L., 2004. In: Larsen, J., Nguyen, N.L. (Eds.), *Potentially Toxic Microalgae of Vietnamese Waters: Opera Botanica*, Copenhagen, Denmark, 140, 216 pp.
- Lorenzen, C.J., 1967. Determination of chlorophylls and phaeopigments: spectrophotometric equations. *Limnol. Oceanogr.* 12, 343–346.
- Lu, D., Huang, W., 1999. *Phaeocystis* bloom in southeast China coastal waters 1997. *Harmful Algal News* 19, 9.
- Medlin, L., Zingone, A., 2007. A taxonomic review of the genus *Phaeocystis*. *Biogeochemistry* 83, 3–18. doi:10.1007/s10533-007-9087-1 13.
- Nejstgaard, J.C., Tang, K.W., Steinke, M., Dutz, J., Koski, M., Antajan, E., Long, J.D., 2007. Zooplankton grazing on *Phaeocystis*: a quantitative review and future challenges. *Biogeochemistry* 83, 147–172.
- Nguyen, N.L., Doan, N.H., Andersen, P., Ho, V.T., Skov, J., Chu, V.T., Do, T.B.L., 2004. Occurrence of potentially toxic algae in Vietnamese coastal waters. In: Larsen, J., Nguyen, L.N. (Eds.), *Potentially toxic microalgae of Vietnamese waters: Opera Botanica*, Copenhagen, Denmark, 140, pp. 159–180.
- Nguyen, N.L., Doan, N.H., 1996. Harmful marine phytoplankton in Vietnam waters. In: Yasumoto, T., Oshima, Y., Fukuyo, Y. (Eds.), *Harmful and Toxic Algal Blooms*. Intergovernmental Oceanographic Commission of UNESCO, pp. 45–48, 586 pp.
- Nguyen, N.L., Doan, N.H., Pham, T.V., 1997. Outbreak of *Noctiluca scintillans* (Mac.) Ehr. related to eutrophication in Vanphong-Bengoi Bay, Central Vietnam. In: Viger, G., Ong, K.S., McPherson, C., Millson, N., Watson, I., Tang, A. (Eds.), *Proceeding of the ASEAN-Canada Technical Conference on Marine Science (24–28 June, 1996)*, Penang, Malaysia. EVS Environment Consultant, North Vancouver and Dept. of Fisheries Malaysia: ASEAN Mar. Env. Management: Quality Criteria and Monitoring for Aquatic Life and Human Health Protection, pp. IX-29–IX-35.
- Okubo, A., 1971. Oceanic diffusion diagrams. *Deep-Sea Res.* 18, 789–802.

- Rousseau, V., Chrétiennot-Dinet, M.-J., Jacobsen, A., Verity, P., Whipple, S., 2007. The life cycle of *Phaeocystis*: state of knowledge and presumptive role in ecology. *Biogeochemistry* 83, 29–47.
- Schoemann, V., Becquevort, S., Stefels, J., Rousseau, V., Lancelot, C., 2005. *Phaeocystis* blooms in the global ocean and their controlling mechanisms: a review. *J. Sea Res.* 53, 43–66.
- Verity, P.G., Brussaard, C.P.D., Nejstgaard, J.C., Van Leeuwe, M.A., Lancelot, C., Medlin, L. K., 2007. Current understanding of *Phaeocystis* ecology and biogeochemistry, and perspectives for future research. *Biogeochemistry* 83, 311–330.
- Whipple, S.J., Patten, B.C., Verity, P.G., 2005. Life cycle of the marine alga *Phaeocystis*: a conceptual model to summarize literature and guide research. *J. Mar. Syst.* 57, 83–110.
- Widdel, F., Bak, F., 1992. Gram-negative mesophilic sulfate-reducing bacteria, In: Balows, A., Trüper, H.G., Dworkin, M., Harder, W., Schleifer, K.-H. (Eds.), *The Prokaryotes*, 2nd ed. Springer, Berlin, Germany, pp. 3352–3378.