**Photoacclimation strategies in the toxic cyanobacterium Nodularia spumigena**

(Nostocales, Cyanobacteria)

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This ecophysiological study of the planktonic cyanobacterium strain *Nodularia spumigena* (BA-15) was conducted at three photosynthetic active radiation (PAR) irradiances (10, 150, and 290 µmol photons m$^{-2}$ s$^{-1}$) and two temperatures (15 and 30°C). The filament concentration, pigment composition, and photosynthetic performance of *N. spumigena* depended on culture conditions. The cyanobacterium was very tolerant of the highest irradiance at the lower temperature (15°C). Filament concentration, however, was lower at the higher temperature and the highest irradiance compared with other culture conditions. The efficiency ($
\alpha$) and maximum rates of photosynthesis ($\Phi_{\text{m}}$) were both affected negatively at 30°C under irradiances of 150 and 290 µmol photons m$^{-2}$ s$^{-1}$. The photoacclimation capacity of the cyanobacterium was evaluated by analysing pigment concentration (chlorophyll, carotenoids, phycobilins), the photosynthetic light response curves (P-E), and chlorophyll $a$ fluorescence. The highest concentrations of phycobilins and chlorophyll $a$ per 100 µm of filament were observed at 10 µmol photons and the lowest at 290 µmol photons m$^{-2}$ s$^{-1}$. Two photoacclimation mechanisms were identified in *N. spumigena* based on P-E, namely, changes in the number of photosynthetic units and changes in size. The minimum value of $P_{\text{c}}$ (about 5 µmol photons m$^{-2}$ s$^{-1}$) and $P_{\text{r}}$ (about 150 µmol photons m$^{-2}$ s$^{-1}$) is close to those reported for shade-tolerant plants, while the maximum value of $P_{\text{c}}$ (about 100 µmol photons m$^{-2}$ s$^{-1}$) and $P_{\text{r}}$ (about 400 µmol photons m$^{-2}$ s$^{-1}$) is close to those noted in heliophyloids plants. Fluorescence measurements of *N. spumigena* indicated that high irradiance had a negative effect on both $F_{\text{m}}/F_{\text{m}}$ and $\Phi_{\text{PSII}}$, but the effect was more pronounced in the case of $\Phi_{\text{PSII}}$. The tolerance of this planktonic cyanobacterium to elevated light levels explains to some degree why it occurs regularly in marine waters worldwide in summer and often forms toxic blooms.

**KEY WORDS:** Carotenoids, Chlorophyll $a$, Fluorescence, Irradiance, *Nodularia spumigena*, Photosynthesis, Phycobilins

**INTRODUCTION**

The increasing concentrations of nutritive substances noted in coastal waters in the 20th century and the resulting eutrophication support frequent algal blooms world over. Nuisance blooms pose serious environmental problems, and some algal species produce toxins that can cause fish deaths and pose health risks for animals and humans (Blackburn et al. 1996; Kahru et al. 2000; Panosso & Granelli 2000).

Planktonic cyanobacterial strains can frequently dominate other phytoplankton because some of them are able to fix atmospheric nitrogen. Their growth is mainly determined by the availability of phosphorous, which can be stored in cyanobacterial cells. In addition, some cyanobacteria are tolerant of temperature to 70°C and can survive at low irradiances of about 5 µmol photons m$^{-2}$ s$^{-1}$. Moreover, they are able to use dissolved organic matter as a nutrient source. Therefore, when water temperatures increase in summer and the concentration of nutrients in the euphotic zone decreases following intense spring phytoplankton growth, conditions become favourable for the mass development of cyanobacteria (Stal et al. 2003).

Members of the genus *Nodularia* occur in both planktonic and benthic forms and in the surface layer of wet soils.

*Nodularia spumigena* Martens ex Bornet et Flahault 1886, a filamentous planktonic cyanobacterium, is a common species that can be found in diverse habitats. It grows in saltwort ponds (Nordin & Stein 1980) and marine, brackish, and freshwaters (Blackburn et al. 1996; Moisander & Paerl 2000; Hobson & Fallowfield 2001), especially in estuaries, coastal lagoons, and bays. *N. spumigena* forms extensive, often toxic blooms in a range of coastal regions (Bolch et al. 1999; Moisander & Paerl 2000). These always occur at water temperatures over 18°C and during weather conditions conducive to water column thermal stratification (Hobson et al. 1999). Although its optimum irradiance varies (Lehtimäki et al. 1994), *N. spumigena* grows especially well in the illuminated upper layer of the euphotic zone. It also occurs commonly in the Baltic Sea and frequently forms blooms together with other species of cyanobacteria such as *Aphanizomenon flos-aquae* Ralfs ex Bornet et Flahault 1886 (Barker et al. 1999; Kahru et al. 2000; Stal et al. 2003; Wulff et al. 2007; Roleda et al. 2008). In the Baltic Sea, *N. spumigena* is most abundant to depths of 5 m (Hajdu et al. 2007), but it is also observed as deep as 18 m (Stal & Walsby 2000). According to Stal et al. (2003), the most important features that enable *N. spumigena* to dominate other species are as follows: (1) the gas vesicles that regulate buoyancy, (2) N$\text{\textsubscript{2}}$-fixing capabilities, and (3) a low photosynthetic compensation point of about 5 µmol photons m$^{-2}$ s$^{-1}$. Although molecular, genetic and envi-
rnonmental investigations on Baltic N. spumigena have been conducted (Barker et al. 1999; Lehtimäki et al. 1997, 2000; Barker et al. 2000; Moisander & Paerl 2000; Laananen et al. 2001; Moffitt et al. 2001; Stal et al. 2002; Stal et al. 2003; Hajdu et al. 2007), little is known about the ecophysiological features of cyanobacteria or their intraspecies variability.

The objective of this work was to identify the photoacclimation strategies of the Baltic cyanobacterial strain, N. spumigena, in response to irradiance and temperature. The influence of the variation of these factors on filament concentration, pigment content, photosynthesis, and the fluorescence of chlorophyll a was investigated. This information will be useful in describing the photoacclimation mechanisms of cyanobacteria, understanding the formation of toxic cyanobacterial blooms worldwide, and developing tools to predict bloom formation.

MATERIAL AND METHODS

The experiments were conducted on the toxic, planktonic cyanobacterium strain N. spumigena (BA-15). The strain was isolated from the coastal zone of the Gulf of Gdański (southern Baltic Sea) and is maintained as a unialgal culture in the Culture Collection of Baltic Algae (http://www.ocean.univ.gda.pl/~ccba) at the Institute of Oceanography, University of Gdańsk, Poland (Latala et al. 2006).

Experimental conditions

The batch cultures were grown in sterilized BG-11 medium in 300-ml glass Erlenmeyer flasks. The media were prepared from Baltic water with a salinity of 8 psu. The cultures have not been proved to be axenic, but microscopic observations of them did not indicate any bacterial contamination. The incubation vessels were kept in incubators equipped with fluorescent lamps (Sylvania cool-white 40-W and Sylvania 100-W halogen lamps for more intense light). The intensity of PAR was measured with a Li Cor LI-189 quantum-meter with a cosine collector. The influence of combinations of PAR irradiance (10, 150, and 290 μmol photons m$^{-2}$ s$^{-1}$) and temperature (15 °C and 30 °C) on N. spumigena was tested in a 16:8 h L:D cycle. The cultures were acclimated to every combination for 7 days. These cultures were the inocula for experimental cultures, and the initial number of filament units in them was 5000 per ml (1 filament unit = 100 μm). Similarly as in the Baltic Monitoring Programme, a filament of 100-μm length was accepted as filament unit (Kononen 1992). Experimental cultures were grown in three replicates and were incubated for 21 days in a factorial combination of light and temperature. On the last day of incubation in the exponential growth phase, the concentration of filaments, pigment content, gas exchange, and fluorescence were measured in each replicate.

Filament concentration

The number of filament units was measured microscopically using Millipore White Gridded HAWG filters (47 nm). The optical density (OD) of the test cultures was measured spectrophotometrically at 750 nm with a DU 530 Beckman UV-VIS spectrophotometer. These data provided the basis for determining the correlation coefficient (r = 0.98) and the linear correlation (y = 1243137.94x – 6092.73, where y = number of filament units and x = OD). The number of filament units in the test cultures was determined from the calibration curve.

Pigment concentration

The same type of spectrophotometer as above was used to take measurements of photosynthetic pigments. Chlorophyll a and carotenoids were extracted with cold 90% acetone in the dark for 2 hours at −20°C. The concentration of carotenoids was calculated according to Strickland & Parsons (1972) with the formula Car [μg/ml] = 4(Ε480 – Ε570)•V_a/V_b, while the concentration of chlorophyll a was estimated with the formula Chl a [μg/ml] = 11.236(Ε665 – Ε750)•V_a/V_b, derived from a factor by Strickland & Parsons (1972), where V_a = extract volume [ml] and V_b = sample volume [ml]. Phycobilins were extracted according to Stewart & Farmer (1984). Each filter was thoroughly homogenized in a medium of 0.25 M Trizma Base, 10 mM disodium EDTA, and 2 mg ml$^{-1}$ lysozyme. The pH of the medium was adjusted to 5.0 with HCl. Homogenates were incubated in the dark for 2 hours at 37°C and then for 20 hours at 2°C. The concentration of phycobilins was calculated according to Tandeau de Marsac & Houmard (1988):

\[
\text{phycocyanin (PC) [mg/ml]} = \left[\frac{(E_{620} - E_{750}) - 0.7\cdot(E_{650} - E_{750})}{V_a/V_b}\right]7.38^{-1}\cdotV_a/V_b;
\]

\[
\text{allophycocyanin (AP) [mg/ml]} = \left[\frac{(E_{650} - E_{750}) - 0.19\cdot(E_{620} - E_{750})}{V_a/V_b}\right]5.65^{-1}\cdotV_a/V_b
\]

where V_a and V_b are as above. These formulas were derived using equations by Bennett & Bogorad (1973) and the extinction coefficients from Bryant et al. (1979). Tandeau de Marsac & Houmard (1988) suggested that these equations can be used for all cyanobacterial strains since the interpretation of results depends on a comparison of the pigment composition of the organism studied after growth under different light conditions and not on the absolute values of phycobiliprotein content. The results for phycobilins are presented as the sum of PC and AP expressed in pg/filament unit.

Gas exchange rate

Photosynthesis and dark respiration rates were measured with a volumetric microrespirometer (Zurzycki & Starzecki 1971). Photosynthetic light response curves (P-E) were determined for N. spumigena grown under different light and temperature conditions. To estimate P-E curve, the algal samples were always taken from the dark phase of the L:D cycle. Firstly, dark respiration was determined. Oxygen production was determined within a range between 0 and 670 μmol photons m$^{-2}$ s$^{-1}$. The PAR irradiance source was a 75 W halogen lamp (Osram). Light intensity was
controlled by neutral density filters, and irradiance was measured using a Li Cor LI-189 quantum-meter with a cosine collector. At each irradiance, the sample was illuminated for about 10 minutes.

**Chlorophyll fluorescence**

Chlorophyll $a$ fluorescence was measured with a Hansatech FMS 1 Pulse Amplitude Modulation (PAM) fluorometer. All light sources required for the modulated measurement of fluorescence parameters are contained within the instrument: 594-nm amber modulating beam, dual-purpose halogen actinic/saturating pulse lamp, and 735-nm far-red LED source. Fluorescence parameters were determined after about 30 minutes of dark adaptation. The PAM method is useful for estimating the following fluorescence variables: $F_o$, $F_m$, $F_v$, $F_p$, and $F'_m$ (Maxwell & Johnson 2000). $F_o$ is the fluorescence level of dark-acclimated samples (all photosystem II [PSII] electron acceptors fully oxidized and reaction centres open), $F_m$ is the maximum fluorescence level at a saturating radiation pulse in dark-acclimated samples, $F_v$ is the maximum variable fluorescence of dark-acclimated samples (the difference between $F_m$ and $F_o$), $F_p$ is the steady-state fluorescence level of samples under the ambient light regime, and $F'_m$ is the maximum fluorescence level of light-acclimated samples. FMS software allows programming protocols to estimate the maximum PSII quantum efficiency of dark-acclimated samples ($F_v/F_m$) and effective PSII quantum efficiency of samples illuminated with irradiance values used in the test cultures ($\Phi_{PSII} = (F'_m - F_o)/F'_m$).

**Statistical analyses**

All experimental variants were run in triplicate. The effect of PAR irradiance and temperature on the concentration of filaments, pigment content, gas exchange, and fluorescence parameters were compared by analysis of variance (ANOVA) at a confidence level of $P < 0.05$, and statistical calculations were performed using the STATISTICA® 6.0 program. The significance between pairs of variable means was determined with least significant difference (LSD) analysis. LSD analysis was applied only if ANOVA indicated significant differences between the variable means of PAR irradiance and temperature (Snedecor & Cochran 1980).

Photosynthetic rates, normalized to chlorophyll $a$ and filament units, were plotted against irradiance. The P-E curves were fitted to the data with STATISTICA using the mathematical function by Platt & Jassby (1976), as follows: $P = P_m \cdot \tanh(\frac{\alpha \cdot E}{P_m}) + R_d$, where $P = \text{photosynthesis rate}$, $P_m = \text{maximum rate of photosynthesis}$, $\alpha = \text{initial slope of the photosynthetic curve}$, $E = \text{irradiance}$, and $R_d = \text{dark respiration}$. Correlation coefficients for the given P-E curves were always higher than 0.900. Photosynthetic parameters, such as compensation point ($P_c$) and saturation irradiance ($E_s$), were determined mathematically. The values of the saturation point ($P_s$) were estimated by extrapolating the light-limited part of the P-E curve up to the $P_m$ value and by reading the irradiance value.

**RESULTS**

**Filament concentration**

*N. spumigena* filament concentration ($P < 0.001$) was affected by culture conditions (Fig. 1). The results of variance analysis indicated that the influence of irradiance on culture density was greater than that of temperature or the interaction of both factors. At 15°C, the highest filament concentration occurred in the high light (290 μmol photons m$^{-2}$ s$^{-1}$) treatment, and it was 90% higher in comparison to the low-light treatment of 10 μmol photons m$^{-2}$ s$^{-1}$ and 35% higher as compared to the medium-light treatment of 150 μmol photons m$^{-2}$ s$^{-1}$. Conversely, at 30°C, the highest filament concentration was noted in the medium-light treatment, and the lowest was in the high-light treatment. In the medium-light treatment, the differences between the numbers of filament units (x10$^5$ ml$^{-1}$) were not statistically significant ($P > 0.05$) at both temperatures.

**Photosynthetic pigments**

The concentrations of chlorophyll $a$ and phycobilins, expressed per filament unit, were negatively affected by irradiance ($P < 0.001$) (Fig. 2). Chlorophyll $a$ concentrations were about 85% higher in the cyanobacteria acclimated to the low-light treatment in comparison to the high-light treatment at both temperatures tested. Similar differences were noted in the case of phycobilins. At both temperatures and low light, their amounts were over 90% higher compared to the high-light treatment. The carotenoid concentrations in the filaments were not altered by irradiance at either of the temperatures tested ($P > 0.05$) (Fig. 2). The results of variance analysis showed that the influence of temperature on pigment concentration was lower than that of irradiance. It was also indicated that the mean pigment concentration values were always higher at 30°C than at 15°C. However, in the high-light treatment, the differences in carotenoid and phycobilin concentrations were not statistically significant ($P > 0.05$).
Photosynthetic parameters

The maximum photosynthesis rates ($P_m$) expressed per filament unit ($\mu l\cdot10^{-2}O_2\cdot (\text{filament unit}\cdot\text{sec})^{-1}$) were the highest in the low-light treatment and the lowest in the high-light treatment. The differences between the mean values ($P < 0.001$) were 2.5 and 5.8 times at 15°C and 30°C, respectively. Similarly, the highest filament-specific $a$ parameter was observed in the low light and the lowest in the high light ($P < 0.001$). Conversely, the mean values of oxygen consumption were higher in the high-light treatment than in the low-light treatment, and at 30°C, the values differed about 78%, while at 15°C, the difference was not statistically significant ($P > 0.05$). Much higher differences were noted in compensation point ($P_c$). This parameter was about 90% and 96% higher for cultures grown in the high-light treatment as compared to those from the low-light treatment at 15°C and 30°C, respectively.

For cultures grown at 15°C, the chl $a$-specific $P_m$ ($\mu l\cdot10^{-2}O_2\cdot (\mu g\text{ chl} a)^{-1}\cdot\text{sec}^{-1}$) was 65% higher ($P < 0.001$) in the cyanobacteria acclimated to high light than in those acclimated to low light (Fig. 4, Table 2). At 30°C, that difference was slight but statistically significant at a confidence level of $P < 0.01$. However, oxygen consumption was about 90% and 96% higher in the high-light treatment as compared to that in the low-light treatment at 15 and 30°C, respectively. In contrast, the mean values of chl $a$-specific $a$ were similar at different growth irradiances ($0.145-0.158$ and $0.044-0.053 \mu l\cdot10^{-2}O_2\cdot (\mu g\text{ chl} a)^{-1}\cdot\text{sec}^{-1}$ at 15°C and 30°C, respectively), and the results of variance analysis indicated that the influence of irradiance on chl $a$-specific $a$ was not statistically significant ($P > 0.05$).

The results of variance analysis showed that temperature and its interaction with light also had an effect on photosynthesis ($P < 0.001$). High temperature was noted to have a negative impact on both the maximum rates of photosynthesis ($P_m$) and the $a$ parameter (Tables 1 and 2). Only in the cultures grown in low light, the filament-specific $P_m$ was about 30% higher at 30°C than at 15°C.

Fluorescence parameters

The effect of growth irradiance ($P < 0.001$) on in vivo chlorophyll fluorescence is shown in Fig. 5. $F_v/F_m$ was higher by about 68% and 76% in the low-light treatment in comparison to the high-light treatment at 15°C and 30°C, respectively. However, analogous differences in mean $\Phi_{PSII}$...
values were about 86% and 96% higher in the low-light than in the high-light treatment.

The results of variance analysis also indicated that PSII quantum efficiency was affected by temperature ($P < 0.001$). Both $F_v/F_m$ and $\Phi_{PSII}$ were lower at 30°C than at 15°C. The differences in cultures grown in the low- and medium-light treatments were about 40% for both parameters, whereas in the high-light treatment the differences were 54% and 78% for $F_v/F_m$ and $\Phi_{PSII}$, respectively.

**DISCUSSION**

Every phototrophic organism has a distinct light intensity range within which it grows and photosynthesizes. This is genetically determined and controlled by the metabolic properties of each species (Richardson et al. 1983). Cyanobacteria are generally recognized to prefer low light intensity for growth and photosynthesis (Fogg & Thake 1987; Ibelings 1996). However, the investigated strain of *N. spumigena* was found to be well acclimated to relatively high light intensity (290 µmol photons m$^{-2}$ s$^{-1}$), which was especially evident at the low treatment temperature (15°C). Similarly, Roleda et al. (2008) suggested that *N. spumigena*...
was able to acclimate to a high light intensity of 300 μmol photons m\(^{-2}\) s\(^{-1}\) at a temperature of 17°C, with a corresponding increase in \(E_k\) and a maximum relative electron transport rate (\(rETR_{max}\)). In the present work, the highest \(N.\) spumigena filament concentration was noted at 290 μmol photons m\(^{-2}\) s\(^{-1}\) and 15°C. Conversely, the combination of 290 μmol photons m\(^{-2}\) s\(^{-1}\) and 30°C significantly limited filament concentration as well as the efficiency (\(\alpha\)) and maximum rate of photosynthesis (\(P_m\)). Prolonged exposure to high light intensity may cause photoinhibition and induce harmful effects resulting from increased temperatures (Davison 1991; Ibelings 1996). A similar phenomenon was observed in the benthic strain of Baltic cyanobacterium Phormidium amphibium (Ag. ex Gom.) Anagnostidis & Komárek 1988, namely, that its filament concentration decreased at 32–35°C and 145–170 μmol photons m\(^{-2}\) s\(^{-1}\) (Latała & Misiewicz 2000). Richardson et al. (1983) suggested that the photoinhibition of growth and photosynthesis occurred in natural populations at irradiances above 200 μmol photons m\(^{-2}\) s\(^{-1}\); however, this phenomenon can occur in many species at lower irradiances. The current experiments with \(N.\) spumigena did not indicate photosynthetic photoinhibition until approximately 700 μmol photons m\(^{-2}\) s\(^{-1}\), while Moisander et al. (2002) did not note this phenomenon in
N. *spumigena* even at irradiances exceeding 1000 μmol photons m$^{-2}$ s$^{-1}$. In the Baltic Sea, *N. spumigena* is distributed from the surface layer, where summer light intensity is as high as 1500–2000 μmol photons m$^{-2}$ s$^{-1}$, to the thermocline (20–25 m) (Stal et al. 2003). Thanks to their gas vesicles and the ability to form aggregations, *N. spumigena* can occupy the most favourable section of the water column. Stal & Walsby (2000) reported that the largest concentrations of *N. spumigena* occurred in the Baltic Sea to about 7 m at about 15°C and 140–200 μmol photons m$^{-2}$ s$^{-1}$ during the summer months. However, Lehtimäki (1997) found *N. spumigena* growth maxima at light intensities of 105–155 μmol photons m$^{-2}$ s$^{-1}$ and temperatures of 20–25°C. Thus, the results obtained for *N. spumigena* under laboratory conditions correspond well with those from the natural environment.

The differences in the filament concentration of *N. spumigena* acclimated to different light conditions were likely attributable to the photoprotective role of the carotenoid pigments. Carotenoids limit the photoinhibition damage of the photosynthetic apparatus. *N. spumigena* exhibited good acclimation capacity to light conditions.

Cyanobacteria are photoautotrophic organisms with phycobilins as the major light-harvesting pigments. The amount of these pigments in cyanobacteria cells varies depending on irradiance. The *N. spumigena* from the low-light treatment in the current study had a phycobilin content than was approximately 10 times that of the cyanobacteria from the high-light treatment, which indicates that light quanta was being used optimally. Similar effects have been reported in experiments on many strains of cyanobacteria, such as *Anabaena* sp. PCC 7120 (now strain assigned to *Nostoc*) (Belknap & Haselkorn 1987), *Synechococcus* sp. PCC 6301 (Kalla et al. 1989), *Calothrix* sp. PCC 7601 (now strain assigned to *Tolypothrix*) (Tandeau de Marsac et al. 1990), *O. agardhii* Gomond 1892 (Millie et al. 1990), and *A. circinalis* Rabenhorst ex Bornet & Flahaut 1888 (Millie et al. 1992).

The lower cellular content of chlorophyll a noted in the population acclimated to high light is associated with a decrease in the size and/or the number of photosynthetic units (PSUs) that can be reflected by P-E curves (Platt et al. 1980; Prézelin 1981; Ramus 1981; Richardson et al. 1983; Henley 1993; Dring 1998; Mouget et al. 1999; MacIntyre et al. 2002). Figures 3 and 4 illustrate that *N. spumigena* conforms to more than one of the photoadaptive models used to categorize species (Prézelin 1981; Richardson et al. 1983). The filament-specific P$_{m}$ noted in the strain acclimated to low light was higher than that grown in the high-light treatment, which indicates a change in the number of the PSUs. However, higher chl a-specific P$_{m}$ in the strain acclimated to high light in comparison to that in the low-light strain indicates there was a change in the size of the PSUs.

It is typical for E$_{k}$ and P$_{s}$ values to increase in phototrophic populations as irradiance increases (Richardson et al. 1983); whereas, the link between the evolution of light intensity compensation (P$_{c}$) and increased irradiance is somewhat more characteristic of Chlorophyta (Falkowski & Owens 1980). It is noteworthy that *N. spumigena* exhibits substantial changes in P$_{c}$ and P$_{r}$ within the irradiance range tested. The minimum value of P$_{r}$ (about 5 μmol photons m$^{-2}$ s$^{-1}$) is close to those reported for shade-tolerant plants, while the maximum value (about 100 μmol photons m$^{-2}$ s$^{-1}$) is close to those noted in heliophyous plants (Rabinowitch 1951; Wallentinus 1978). The maximum value of P$_{r}$ (about 400 μmol photons m$^{-2}$ s$^{-1}$) indicates that *N. spumigena* is heliophyous, while the minimum value (about 150 μmol photons m$^{-2}$ s$^{-1}$) indicates it has shadow-tolerant features. The P$_{c}$ and E$_{k}$ parameters presented by Stal & Walsby (2000) for the growth of a *Nodularia* spp. strain at 15°C and 20–30 μmol photons m$^{-2}$ s$^{-1}$ were about four times higher than those in the present work under similar conditions.

The values of F$_{v}$/F$_{m}$ and F$_{PSII}$ can provide additional information concerning the photosynthetic apparatus (Maxwell & Johnson 2000). Fluorescence measurements of *N. spumigena* indicated that high irradiance had a negative effect on both F$_{v}$/F$_{m}$ and F$_{PSII}$, but it was higher in the case of F$_{PSII}$. *N. spumigena* coped well with high irradiance damage by closing PSII reaction centres, thus reducing the quantity of absorbed energy used in photochemical processes. Similar changes in values of F$_{v}$/F$_{m}$ were noted by Wulff et al. (2007) and Roleda et al. (2008) in experiments on strains of *N. spumigena* from the Kalmar Algae Collection – KAC (Sweden).

The current experiments on *N. spumigena* demonstrated its capacity to acclimate to irradiance. The cyanobacteria were able to alter quantities of photosynthetic pigments to better use light quantum and also to provide protection from the unfavourable effects of excessive light. This explains why *N. spumigena* grows successfully in both well-illuminated surface waters and deeper waters (Stal & Walsby 2000; Stal et al. 2003). Its depth distribution is most likely due to species-specific adaptations to light and temperature. The identification of factors that regulate the growth and photosynthetic activity of this problematic species can be helpful for understanding the ecological triggers of cyanobacterial blooms.

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