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生态学报

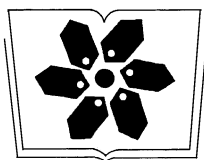
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生态学报

(SHENGTAI XUEBAO)

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封面图说: 带雏鸟的白枕鹤一家——白枕鹤是一种体型略小于丹顶鹤的优美的鹤。体羽蓝灰色,腹部较深,背部较浅,脸颊两侧红色,头和颈的后部及上背为白色,雌雄相似。其虹膜暗褐色,嘴黄绿色,脚红色。白枕鹤常常栖息于开阔平原芦苇沼泽和水草沼泽地带,有时亦出现于农田和海湾地区,尤其是迁徙季节。主要以植物种子、草根、嫩叶和鱼、蛙、软体动物、昆虫等为食。繁殖区在我国北方和西伯利亚东南部。我国白枕鹤多在黑龙江、吉林、内蒙古繁殖,与丹顶鹤的繁殖区几乎重叠,为国家一级保护动物。

彩图提供: 陈建伟教授 北京林业大学 E-mail: cites.chenjw@163.com

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何虎,何宇虹,姬娅婵,郭亮,刘正文,李宽意. 蓝藻堆积和螺类牧食对苦草生长的影响. 生态学报, 2012, 32(17): 5562-5567.

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蓝藻堆积和螺类牧食对苦草生长的影响

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摘要: 设计了双因素四组处理(对照组, 加螺组, 加藻组, 螺藻组)的室外受控实验, 模拟湖泊沿岸带水华蓝藻的堆积以及底栖螺类的牧食活动对沉水植物苦草生长的影响。结果表明: 蓝藻堆积(水体叶绿素 a 浓度为 220 $\mu\text{g/L}$)对苦草的生长具有明显的抑制作用, 和对照组以及加螺组相比, 加藻组和螺藻组中苦草的相对增长率分别下降了 40.9% 和 36.4%, 分株数也分别下降了 56.4% 和 64.1%, 分析认为蓝藻在水体表层堆积所产生的遮光可能是抑制底层苦草生长的主要原因。然而, 环棱螺能在一定程度上促进苦草的生长, 加螺组和螺藻组中苦草的相对增长率和分株数分别要明显高于对照组和加藻组, 这可能要归因于螺类的牧食去除了沉水植物表面附着生物。实验中蓝藻堆积和螺类牧食对苦草的各项生长指标均无显著的交互作用, 但蓝藻对苦草生长的抑制作用要远大于螺类对植物生长的促进作用。研究证实了在富营养浅水湖泊中, 水华蓝藻在湖泊沿岸带的堆积会严重胁迫沉水植物的生长, 而底栖螺类的牧食活动则能在一定程度上提高植物在不良环境下的生存能力。

关键词: 蓝藻水华; 铜锈环棱螺; 苦草; 生长

Effects of cyanobacterial accumulation and snail grazing on the growth of *vallisneria natans*

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Abstract: Cyanobacterial blooms is a common phenomenon in large shallow eutrophic lakes such as Lake Taihu, China. When it occurs, a dense algal mass may accumulate in the littoral zone under the action of wind and waves. This algal layer at the surface water can last for a few days and may pose negative influences on local aquatic plants, especially submerged macrophytes. However, there is a severe lack of studies to evaluate the impacts by the algal bloom formation. A great deal of studies showed that some benthic snails can promote the growth of submerged aquatic plants by their grazing activities in clear water lake ecosystems, but in turbid lakes with high concentrations of cyanobacteria, whether the snails still have positive impacts on the growth of submerged plants remains unclear. Here, we conduct a mesocosm experiment with a 15-day duration to explore the influence of cyanobacterial accumulation and snail grazing on the growth and reproduction of

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submerged aquatic plants. In this experiment, snail *Bellamya aeruginosa*, submerged macrophyte *Vallisneria natans* and cyanobacteria were selected from Meiliang Bay of Lake Taihu, China. Our experiment design included four treatments (control, snails only, cyanobacteria only and snails & cyanobacteria). Results showed that high concentrations of cyanobacteria ($\text{Chl-a} > 220 \mu\text{g/L}$) strongly inhibited the growth of *V. natans*. Compared to the control group, the relative growth rate of *V. natans* in cyanobacteria only group decreased by 40.9%. Meanwhile, the relative growth rate of plants in cyanobacteria & snails treatment group was also 36.4% lower than those in snails only group. Moreover, high concentrations of cyanobacteria suppressed the reproduction of *V. natans*. The number of *Vallisneria* ramets in the cyanobacteria only and cyanobacteria & snails group were 56.4% and 64.1% lower than that in the control and snails only groups, respectively. The poor growth and reproduction in treatments with high cyanobacterial concentrations are likely attributed to the shading effect of cyanobacterial blooms on submerged aquatic plants. However, the grazing activities of *B. aeruginosa* could promote the growth and reproduction of macrophytes in treatments with or without the presence of algal layer. In this experiment, the relative growth rate and number of ramets in snails only and snails & cyanobacteria treatments were evidently higher than those in the control and the cyanobacteria only treatments, respectively. This might be due to the removal of periphyton which adhered to the surface of aquatic plants by the grazing activities of snails *B. aeruginosa*. Two-Way Analysis of Variance showed that the interactive effects of two factors (cyanobacterial accumulation & snail grazing) in this experiment were no significant and the influence of cyanobacterial accumulation on the growth of *V. natans* was greater than that of snail grazing. This study suggested that in large shallow eutrophic lakes, the accumulation of cyanobacteria in the downwind littoral zones could seriously suppress the growth of the submerged aquatic plants in several days, but the grazing activities of snails can, to some extent, reduce the impacts by the cyanobacterial blooms and enhance survival ability of plants in the cyanobacteria impacted environments.

Key Words: cyanobacterial blooms; *Bellamya aeruginosa*; *Vallisneria natans*; growth

蓝藻水华是我国富营养浅水湖泊(如太湖、巢湖和滇池)中的一个常见现象^[1-4],水华蓝藻的暴发往往伴随着湖泊水生植被的衰退。以太湖为例,该湖泊近10年来几乎每年都暴发蓝藻水华^[5],从2004年到2007年,太湖水华蓝藻的最大集聚面积从196.8 km²上升到了979.1 km²,与此同时,全湖水生植被的覆盖面积从482.2 km²下降到了364.1 km²,总生物量也下降了23%^[3,6]。观察发现,水华蓝藻能够随风向发生漂移并在湖泊的下风向水域发生堆积^[7],例如位于太湖北部的梅梁湾和竺山湾就是水华蓝藻聚集的重灾区^[3],调查发现这两个湖湾的水生植物的总生物量要明显低于太湖其他区域^[8]。水华蓝藻在湖泊沿岸带的堆积通常具有时间短,浓度高的特征,这种堆积是否抑制了当地生境内水生植物的生长或者繁殖,甚至进一步导致了水生植被的衰退?浅水湖泊的湖滨带经常分布有大量的底栖螺类,研究发现某些螺类的牧食活动能够促进生境内沉水植物的生长^[9-10],例如,Underwood等^[11]发现扁蜷螺(*Planorbis planorbis*)的存在有利于金鱼藻(*Ceratophyllum demersum*)的生长,李宽意等^[12]通过实验证明了铜锈环棱螺(*Bellamya aeruginosa*)与苦草(*Vallisneria spiralis*)之间存在互利关系。然而,类似的试验多是在无藻类水华的水体中进行,而在水华蓝藻大量堆积的湖泊沿岸带,生境内底栖螺类的牧食活动是否依然能促进沉水植物的生长还不得而知。基于此,在太湖梅梁湾岸边设计了一个两因素的受控实验,以太湖沿岸带常见的沉水植物苦草(*V. natans*)和铜锈环棱螺(*B. aeruginosa*)为实验材料,模拟短期内(15 d)水华蓝藻的堆积覆盖以及底栖螺类的牧食活动对沉水植物生长的影响,研究成果有助于理解湖滨带生态系统中各生物因子之间的相关关系。

1 材料与方法

实验在聚乙烯塑料桶中进行,桶高70 cm,上下底直径分别为50 cm和35 cm。每桶放入10 cm厚湖泥并注入50 cm深湖水,湖泥和湖水均来自太湖梅梁湾,分别经过60目筛网和300目筛绢过滤,湖泥初始总氮和总磷浓度分别为(1.23±0.10) g/kg和(0.89±0.03) g/kg;湖水初始TN和TP浓度分别为(2.67±0.17) mg/L

和 $(78.2 \pm 6.7) \mu\text{g/L}$ 。实验前一周从太湖梅梁湾岸边收集苦草和环棱螺,放在塑料箱中培育待用。

整个实验在露天条件下进行,实验设 2 个影响因子共 4 种处理,每种处理设 4 个重复,共 16 个实验水桶,分别命名为对照组、加螺组、加藻组和螺藻组。5 月 20 日从塑料箱中挑选叶片颜色亮绿、无明显损伤的苦草移栽到各实验桶中,每桶 10 株植物,各桶中植物的株高和湿重基本一致。4 d 后按照实验设计添加水华蓝藻和环棱螺,实验正式开始。蓝藻的添加量通过水体中的叶绿素 a 浓度换算,空白组和加藻组水体的 Chl-a 浓度为 $(25.06 \pm 5.11) \mu\text{g/L}$,加藻组和螺藻组水体 Chl-a 浓度为 $(220.36 \pm 11.48) \mu\text{g/L}$;铜锈环棱螺每桶添加 50 只,总重为 $(5.36 \pm 0.11) \text{g}$ 。为了采集附着生物,在各桶中悬挂塑料板($8 \text{ cm} \times 10 \text{ cm}$)两块,塑料板在桶中的位置一致,塑料板下方悬挂一石块以保持垂直状态。6 月 7 号采集附着生物样品及水样,测定单位面积附着生物的干重,分析水体总溶解性氮磷(TDN & TDP)和叶绿素 a(Chl-a)含量,方法依据《湖泊富营养化调查》^[13]。6 月 8 号实验结束,拔出桶内苦草测定鲜重和分株数,计算苦草的相对生长率,其计算公式如下: $RGR = \ln(W_f / W_i) / \text{天数}$,式中 W_f 和 W_i 分别为实验前后植物的湿重。试验期间对水下 10cm 处光照度和水温进行了监测,并在高于 35°C 时用遮阳网遮盖降温,遮盖时间一般为 11:00—16:00。

2 结果

2.1 对苦草生长的影响

蓝藻水华显著抑制苦草的生长($P < 0.05$),总体来说,水华处理组苦草的生长状况要明显劣于无水华的处理组(图 1 和图 2),说明在本实验中,苦草的生长主要受蓝藻堆积的影响,螺类牧食的影响要居于次要地位。具体而言,加藻组苦草的相对生长率为 $(37.1 \pm 3.2) \text{ mg} \cdot \text{g}^{-1} \cdot \text{d}^{-1}$,低于对照组的 $(62.8 \pm 6.6) \text{ mg} \cdot \text{g}^{-1} \cdot \text{d}^{-1}$,降幅为 40.9%;螺藻组苦草的相对生长率为 $(46.8 \pm 4.8) \text{ mg} \cdot \text{g}^{-1} \cdot \text{d}^{-1}$,同样低于加螺组的 $(73.6 \pm 8.3) \text{ mg} \cdot \text{g}^{-1} \cdot \text{d}^{-1}$,降幅为 36.4%(图 1)。此外,苦草的分株数也明显受水华蓝藻的抑制($P < 0.05$),和对照组(加螺组)相比,加藻组(螺藻组)苦草的分株数下降了 56.4%(64.1%)(图 2)。铜锈环棱螺的牧食活动对苦草的生长具有一定的促进作用,如图 1 和图 2 所示,无论是加螺组之于对照组还是螺藻组之于加藻组,苦草的相对生长率和分株数都有明显提高($P < 0.05$)。方差分析表明,水华蓝藻堆积和螺类牧食活动之间无明显的交互作用($P > 0.05$)。

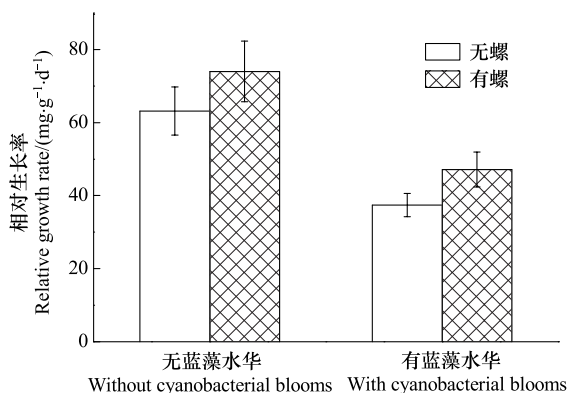


图 1 各组苦草的相对生长率比较

Fig. 1 Comparison of relative growth rate of *V. natans* of four groups

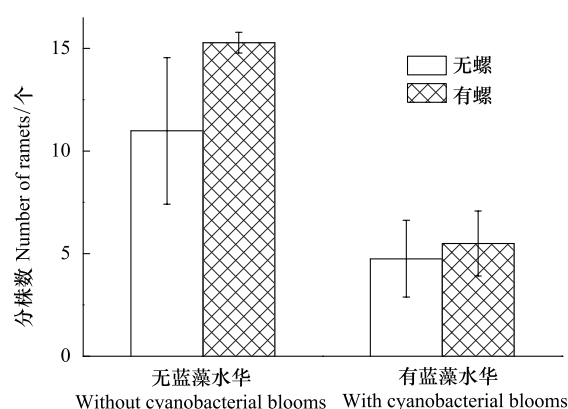


图 2 各组苦草的分株数比较

Fig. 2 Number of ramets of *V. natans* in four treatments

2.2 对附着生物的影响

水华蓝藻对附着生物的影响不显著($P > 0.05$),而螺类牧食则降低了桶内附着生物的生物量($P < 0.05$),二者无明显的交互作用($P > 0.05$)。如图 3 所示,空白组和加螺组附着生物的单位面积干重分别为 $(393.75 \pm 139.53) \mu\text{g/cm}^2$ 和 $(220.00 \pm 155.50) \mu\text{g/cm}^2$,降幅达到了 44.1%;同样的,和加螺组相比,螺藻组附着生物的单位面积干重也下降了 70.1%

2.3 对水体理化指标的影响

实验结束时各处理组上覆水总溶解氮(TDN)和总溶解磷(TDP)的浓度分别在 0.89 mg/L 至 2.30 mg/L 以及 0.012 mg/L 至 0.067 mg/L 之间变化(表 1),和初始值相比均有一定程度的下降。分析发现,加藻组和螺藻组水体的 TDN 和 TDP 浓度要分别高于对照组和加螺组($P<0.05$)。另外,添加水华处理的试验组(加藻组和螺藻组)在整个实验期间 Chl-a 浓度(表 1)下降了 54.4%,说明有部分蓝藻在实验桶内死亡分解。蓝藻水华和螺类牧食对水体的光照度(表 1)具有显著的影响($P<0.01$),蓝藻水华覆盖使得桶内光照度分别削减了 45.3%(无螺)和 53.9%(有螺),相反,螺类牧食则能提高水体透明度,在环棱螺存在的条件下,两个系统的光照度分别提高了 27.2%(无水华)和 7.1%(有水华)。

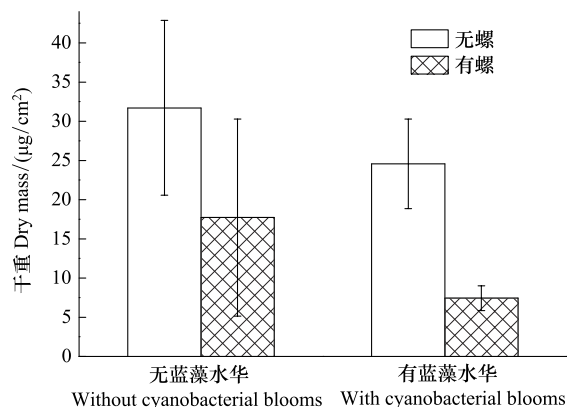


图3 各组单位面积附着生物干重

Fig. 3 periphyton dry mass per unit area of four groups

表 1 实验结束时水体营养盐和叶绿素 a 浓度以及水下光照度比较

Table 1 The comprison of nutrient and Chlorophyll-a concentrations and light intensity in the end of experiment

	总溶解氮 TDN/ (mg/L)	总溶解磷 TDP/ (µg/L)	叶绿素 a Chl-a / (µg/L)	光照度 Light intensity/lx
空白组 Control	1.10±0.17	19.99±3.26	26.39±8.44	3968±270
加螺组 Snails only	1.17±0.20	16.99±3.83	22.38±9.34	5045±460
加藻组 Algae only	1.67±0.36	34.98±22.31	106.10±67.81	2170±414
螺藻组 Snails & algae	1.81±0.37	30.98±9.99	96.38±25.93	2325±194

3 讨论

本实验证明了在短期内(15 d)水华蓝藻堆积(Chl-a>200 µg/L)对沉水植物苦草(*V. natans*)的生长具有明显的胁迫作用,同样的,刘旭博等^[14]研究发现在高浓度水华蓝藻(Chl-a>500 µg/L)覆盖 26d 后,水体底层的苦草(*V. natans*)出现了负生长;陈开宁等^[4]在滇池进行的模拟实验发现竹叶眼子菜(*Potamogeton malaianus*)的生长明显受到蓝藻的抑制,植物在有蓝藻胁迫的水体中生长 22 d 后其生物量下降了 57.1%,而在无蓝藻胁迫的水体中其生物量增加了 24.1%。分析认为,蓝藻堆积在水体表层所产生的遮光效应可能是抑制苦草生长的主要原因。大量研究表明,光照是沉水植物生长的主要限制因子之一^[15-17],例如,朱丹婷等^[18]研究发现,在 5320 lx 光照度下苦草的生长状况明显好于在 1025 lx 光照度下苦草的生长状况,黎慧娟等^[19]也发现弱光照对苦草叶片数有不利影响,Cronin 等^[20]研究发现较低的光照强度不但能够抑制某种眼子菜科植物(*P. amplifolius*)的生长,同时还能够降低对植物地下部分的物质分配。本研究的监测数据表明,水华处理的实验组水下 10 cm 的光照度远远低于无水华的处理组(表 1),所以蓝藻堆积引发的水下光照不足可能是导致苦草的相对生长率降低,分株数减少的主要原因。此外,蓝藻水华释放的微囊藻毒素(Microcystin, MC)也能够抑制苦草的光合作用及其幼苗的发育^[21-22],而在本实验中加藻组和螺藻组有部分蓝藻在实验桶内腐烂分解,这个过程可能有藻毒素释放到水体中,但在短期内是否足以对苦草的生长或繁殖产生抑制还需进一步研究。实验期间各处理组水体的溶解性氮磷含量均有一定程度的下降,在实验结束时,加藻组和螺藻组的 TDN 和 TDP 浓度分别要高于对照组和加螺组,这可能是以下两方面的原因共同造成的:(1)苦草在生长的过程中会吸收水体中的营养盐,使得水体氮磷含量降低^[23-24];(2)蓝藻在实验桶内的腐烂分解向水体释放了营养盐,从而提高溶解性氮磷含量^[25]。

铜锈环棱螺的牧食活动促进了苦草的生长,这与附着生物的生物量减少有关。大量研究表明附着生物对

沉水植物同样具有较强的遮光作用^[26-28],而螺类的牧食活动则能够去除植物表面的附着层,从而提高植物的光合作用效率,间接促进植物的生长^[12, 29]。实验期间经常观察到环棱螺在苦草叶片上活动,而且实验数据也证实了铜锈环棱螺对附着生物具有较高的去除率(图3),与 Li 等^[29]的研究有相似的结论,所以通过本实验可以证实,即使在有水华的环境中,环棱螺的牧食活动依然能够促进苦草的生长。

本试验中蓝藻堆积和螺类牧食对苦草的生长并没有产生显著的交互作用,但二者对苦草生长的影响程度却有差异,蓝藻堆积给苦草生长带来的负面影响要大于螺类牧食对苦草生长的促进作用。水华蓝藻对苦草生长的抑制程度与其浓度有关,浓度越高,抑制作用越强。如果以水体 Chl-a 浓度来衡量蓝藻浓度,在本实验中,Chl-a 浓度为 220 $\mu\text{g/L}$ 左右,在该浓度下植物的生长虽然受到抑制,但仍然表现为正生长;而当 Chl-a 浓度达到 500 $\mu\text{g/L}$ 时,苦草可能会出现负生长^[14];水体 Chl-a 浓度达到 5000 $\mu\text{g/L}$ 时,苦草在 1 周之内就可能全部死亡。同样,螺类对苦草生长的影响程度也与其密度相关, Li 等^[29]研究发现,在 0—640 个/ m^2 范围内,苦草的相对生长率和铜锈环棱螺的密度之间呈正相关关系。本实验中环棱螺的密度约为 460 个/ m^2 ,远高于太湖蓝藻水华暴发最频繁的梅梁湾和竺山湾的年均密度(小于 80 个/ m^2)^[30],然而本研究的蓝藻堆积浓度(220 $\mu\text{g/L}$)要低于大多数水华暴发时期两个湖湾湖滨带蓝藻的堆积浓度(>1000 $\mu\text{g/L}$ 检测值),即使在这种“高螺低藻”的环境下,苦草的生长依然主要受到蓝藻堆积的影响,这说明了在类似于太湖梅梁湾和竺山湾这种高度富营养的湖湾中,苦草的生长状况更多的取决于堆积在水体表层的蓝藻浓度,而底栖螺类的牧食活动只能在某种程度上缓解而不能消除蓝藻水华对苦草生长的不利影响。

4 结论

蓝藻堆积在短期内就会对苦草的生长产生强烈抑制,因此,在富营养的浅水湖泊中,随风漂移到沿岸带的水华蓝藻可能在短期内胁迫生境内沉水植物的生长。与之相反,沿岸带底栖螺类的牧食活动则能够提高沉水植物在不利环境下的生存能力,从而一定程度上延缓沉水植被退化乃至消亡的进程。

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