Asian Agricultural Research 2013, 5(12): 86 – 89, 95

The Effects of Environmental Factors on the Growth and Competition of Algae

Jing WANG[1*], **Jiazhang CHEN**[1,2], **Shunlong MENG**[1,2]

1. College of Fishery, Nanjing Agricultural University, Wuxi 214081, China; 2. Key Laboratory of Ecological Environment and Resources of Inland Fisheries/Freshwater Fisheries Research Center, Chinese Academy of Fishery Sciences, Wuxi 214081, China

Abstract In order to study the effect of environmental factors on the algae growth and competition, the author summarized overseas and domestic related researches in recent years. Most of the researches are about the influence of single factor on growth of algae. However, there is insufficient investment on the interaction of different factors and the competition between algae growth. This paper briefly introduced the classification of algae and the role they played in ecological system and focused on the influence which included temperature, illumination, nitrogen, phosphorus and pH on the growth and competition of algal. In the end, the author proposed key questions which were still needed to be studied in order to know more about the relationship between environment effects and growth and competition of algae. Therefore, people could better improve the community structure of algae and water ecological environment, and improve water primary productivity.

Key words pH, Illumination, Temperature, Nitrogen and phosphorus, Algae

As the primary producer of ecological system, algae not only can produce organics and reduce oxygen, but also impose positive influences on some environmental pollution. People's consumption of water rises amid the industrial and agricultural development and increasing population, thus the eutrophication of water is getting worse and worse. Eutrophication has become a world-wide problem. At present, many lakes, rivers and reservoirs in China are at high eutrophication level. Eutrophication can lead to red tides and bring great loss to the marine and agricultural production, and aquaculture. All-round and deep cooperation is needed to improve the environment and adjust the alga structure. Therefore, the influences of important environment factors such as temperature, sunshine, phosphorus, nitrogen and pH on the growth of alga were summarized so as to provide bases for the relevant study research.

1 Alga categories

There are various kinds of alga. So far, 30 thousand kinds of alga have been identified. Early botanists consider alga and fungi as the same kind of plants, namely thallophyte. With the better understanding of alga, especially after the speech of parallel evolution, alga is not considered as a natural category group, and various independent plyla are set up according to the element, content, compound, flagellum and reproduction method. Although alga is a kind of plant that carries Chlorophyll and it does not have root and leaves. Its reproductive organ is unicellular[1]. There are different opinions on the categories of phyla. Some people think there should be twelve categories, namely *Cyanophyceae*, *Rhodophyceae*, *Cryptophyta*, *Pyrrophyta*, *Chrysophyceae*, *Xanthophyta*, *Bacillariophyta*, *Phaeophyta*, *Euglenophyta*, *Prochlorophyta*, *Chlorophyta*, and *Charophyta*. However, others think there should be nine categories, including *Cyanophyceae*, *Euglenophyta*, *Chrysophyceae*, *Xanthophyta*, *Bacillariophyta*, *Phaeophyta*, *Chlorophyta*, *Rhodophyceae*, and *Phaeophyta*.

2 Influences of algae on aquatic ecosystem

Algae is the foundation of biological resources in the aquatic ecosystem and the basis of material circulation and energy movement in the entire aquatic ecosystem. Whether in the pale water or ocean, algae is the essential preliminary producer in aquatic ecosystem[2] and a key link in the aquatic food chain. As an important bait to zooplankton and aquatic animals, Algae exerts an important role in maintaining ecological balance. As water covers most part of the earth, it is estimated that nearly half organics produced by photosynthesis are from microorganisms such as algae, and those organics are essential constituents of oceanic grass. Through photosynthesis algae can fix inorganic carbon and turn it into carbohydrates so as to provide basis for the production of waters. In the transformation of food chain, from 100 to 1 000 kg of plankton algae is needed to produce 1 kg of fish or meat. Therefore, most of world-renowned fishing grounds lie in waters with abundant algae resources, and the output of planktonic algae has become the indicator to evaluate the preliminary produce of waters.

Algae can absorb nutrient salt such as nitrogen and phosphorous in waters. For algae which is conductive to the digestion of aquatic animals such as fish, its reproduction in waters can reduce the nitrogen and phosphorous, and provide resources for the growth of economic agents so as to improve the preliminary produce of waters. Studies suggest that Chlorella vulgaris can remove the N, P and COD[3-4] in waste water efficiently. However, under

Received: February 27, 2013 Accepted: May 18, 2013
Supported by Special Fund for the Construction of Modern Agriculture Industrial Technological System (CAR – 49); Special Fund for the Basic Scientific Research in Central Public Academies of Sciences (2013JBFM06).
* Corresponding author. E-mail: chenjz@ffrc.cn.

certain conditions, the abnormal increase of algae results in algae bloom and red tide, which would deteriorate the quality of water[5], and kill lots of fishes and shrimps, especially poisonous algae, such as microcystin which can produce toxin that could make people die. The unnatural reproduction of harmful algae brings critical hazards to both aquatic animals and human beings.

3 Influences of major environmental factors on the growth of algae

3.1 Temperature The growth and reproduction of algae is markedly influenced by temperature. The temperature of water imposes influences on the growth of algae in two ways: the biological activity of algae, and the nutrition utilization efficiency. Studies by Shen Zhemin *et al.*[6] suggested that the annual mean temperature increased by 1.0 ℃, and the annual mean algae biomass rose by 0.145 times. Besides, they believed that the more outstanding the eutrophication, the more influences of rising temperature on the growth of algae. Researches by Chen *et al.*[7] indicated that temperature could influence the size of Chlorella vulgaris and the peculiarity of cells. Studies by Yuan Li'na[8] *et al.* proved that when the temperature was lower than 25 ℃, the algae cell reproduced rapidly, and it was concluded that the temperature affected the growth speed and ultimate growth of algae. There were remarkable differences among the effects at the temperature of 10 ℃, 18 ℃ and 25 ℃, and 10 ℃ can restrain the growth of algae distinctively. Zhao Jianyin *et al.*[9] studied the optimum growth rate and competition of Microcystis aeruginosa and Scenedesmus obliquus. Results suggest the optimum temperature for the Scenedesmus obliquus to grow was 25 ℃, which is lower than the optimal temperature for the growth of Microcystis aeruginosa 35 ℃. The algae which is cultivated with other plants grew worse than the one being cultivated alone, which proves that there were restraining effects between different algae and such inhibiting effect either intensified or abated due to the changes of temperature. Studies by Zhu Wei *et al.*[10] proved that when there was competition, the quality concentration of nitrogen and phosphorus was higher than that in Microcystis aeruginosa if the temperature was high, and the quality concentration of nitrogen and phosphorus was lower than that in Microcystis aeruginosa if the temperature was low. High temperature was conductive to the growth of Microcystis aeruginosa, while low temperature was detrimental to the growth of Microcystis aeruginosa. Mild temperature was especially beneficial to the growth and reproduction of Scenedesmus obliquus. Studies by Casazza *et al.*[11] suggested that the temperature rose from 20 ℃ to 25 ℃ and the fat content rose by one times. Studies by Ouyang Zhengrong[11] proved that the temperature for the Chlorella to grow was between 25 and 42.5 ℃ and the optimal temperature was 37.5 ℃. Although various algae grow best at different temperatures, generally speaking, 25 ℃ is the suitable temperature for most algae to grow[13].

3.2 Sunshine Phytoplankton can produce organics through photosynthesis to maintain its' growth and reproduction. The seasonal changes of phytoplankton output are directly linked with the seasonal variations of sunshine conditions[14]. The photosynthesis intensity of phytoplankton depends on the sunshine intensity and light quality. Favorable sunshine intensity and optimum wavelength are the foundation for the growth of algae. Because different kinds of algae have varying optimal intensities of natural light, their competence varied even under the same condition of sunshine level[15]. Studies by Tamburic *et al.*[16] revealed that light can change the amount of H_2 being released to the air by algae. Studies proved that shades can decrease the concentration of algae[17]. Sunshine can increase the synthesis of chlorophyll, but once it passed certain amount, the increasing sunshine level would restrain the synthesis of chlorophyll[18]. Guo Yanqin[19] studied the influences of five kinds of sunshine intensities on algae and found that the higher the sunshine intensity, the faster the cell divides and the higher the biomass. Along with the addition of light intensity, the total photosynthesis kept increasing. When the sunshine intensity reached to a certain amount, the speed of photosynthesis reduced and even stopped.

3.3 Nitrogen and phosphorus The preliminary produce of waters is influenced by nutritional elements N and P in waters. Those nutritional elements are the material foundation of photosynthesis and synthesized organics of phytoplankton, among which N and P are considered as restrictive factors for the breakout of phytoplankton bloom[20-22]. Influences of N and P on the growth of algae include the morphology and the concentration of N and P. Their morphology affects the absorption speed and utilization of N and P, while the N and P concentration influences the growth of algae cell and accumulation of materials in the cell.

3.3.1 Influences of the morphologies of nitrogen and phosphorous on the growth of algae. The nutrient salt can be divided as inorganic source and organic source. Studies by Zhang *et al.*[23] suggest that the optimum nitrogen and phosphorous ratio for the growth of algae differs to different morphologies of nitrogen. Algae uses nitrogen to synthesize protein, but first of all, amino acids are necessary. The nitrogen in inorganic nitrogen is oxidized. Zhang Qingtian *et al.*[24] studied the influences of three different kinds of nitrogen sources on the reproduction of Microcystis aeruginosa on ammonium nitrogen, nitrate nitrogen, and blood urea nitrogen. They found that the optimal ammonium nitrogen concentration for the growth of Microcystis aeruginosa should be 0.5 mmol/L, the optimal concentration of nitrate nitrogen for the growth of Microcystis aeruginosa should be 1.5 – 5.0 mmol/L, and the optimal concentration of blood urea nitrogen for the growth of Microcystis aeruginosa should be 0.5 – 1.5 mmol/L.

Phosphorus which can be directly absorbed by Algae is dissolved organic phosphorus and dissolved inorganic phosphorus[25]. Jing Jiabo[26] used $K_2HPO_4 \cdot 3H_2O$ as the source of inorganic phosphorus and studied its influence on the growth of Microcystis aeruginosa. Study showed that when there was little phosphorus, phosphorus restrained the growth of Microcystis aeruginosa and the growth speed quickened with the increase of phosphorus concentration. Qian Shanle *et al.* [27] used 1 – phosphate-glucose, c – AMP and ATP as the source of soluble phosphorus source, and studied the application of Microcystis aeruginosa and Chlorella pyrenoidesa and their growth. Therefore, Microcystis aeruginosa is more competitive in the eutrophicated water.

3.3.2 Influences of nitrogen and phosphorus concentration on the growth of algae. Generally speaking, nitrogen and phosphorus are restraining the growth of algae in natural waters in two ways. The first one is the absolute concentration of nutrient salt, which would affect the growth of phytoplankton when the absolute concentration of nutrient salt is lower than the threshold value. The second one is the relative concentration ratio of nutrient salt, which can be higher than the threshold value to satisfy the demand for the growth of phytoplankton[28]. Zheng Xiaoyu *et al.* [29] used BG – 11, $NaNO_3$ and K_2HPO_4 to control the initial nitrogen and phosphorus concentration in the experiment Study indicated that cells may need more nitrogen rather than phosphorus and the optimal concentration of nitrogen and phosphorus for the growth of algae were 16.0 – 32.0 mg/L and 2.0 – 5.40 mg/L respectively. Kong *et al.* [30] used yeast to absorb N and P to control the growth of Microcystis aeruginosa. Study by Ruangsomboon *et al.* [31] indicated the concentration of N, P and Fe would affect the growth of lipids in algae. Meng Shunlong *et al.* [32] studied the growth and competition of Microcystis aeruginosa and Oscillatoria princeps, and results proved that Microcystis aeruginosa grew best at the ratio of nitrogen and phosphorus of 4.5, and the Oscillatoria princeps grew best at the ratio of 0.45. Aslan *et al.* [33] concluded that the algae dissolved more nitrogen than phosphorus under the condition of pH 7.0, indoor temperature (20 ± 2) ℃, sunshine 4100 1x, and the ratio of nitrogen and phosphorus. Dong Juan *et al.* [34] calculated that amount of algae cell, DGGE monitoring, and the typical corresponding CCA analysis to study the influences of different nitrogen and phosphorus concentration and the relations among influences of N/P on the algae – fungus structure. Results suggested that the nitrogen and phosphorus concentration and N/P ratio would affect the algae; N/P = 12 being the optimal condition for algae to grow; N/P = 3 and N/P = 48 would restrain algae to grow.

3.4 pH The pH of water affects algae in two ways. Firstly, pH would change the acidity and alkalinity of the water. Too strong acid or too alkaline would harm the algae cell. Only within suitable acid and alkaline range can the algae grow normally. Secondly, pH would affect the carbonate balance system and the distribution of different forms of inorganic carbon. Study found that alkaline water was more likely to grow blue-green algae[35]. pH in the reservoir was mostly determined by the amount of CO_2, while the CO_2 amount would be influenced by many factors, such as water temperature, microorganisms and soluble ion *etc*. Therefore, when there was certain amount of algae, its number and living activity played leading roles in the changes of pH in waters[36]. Wang *et al.* [37] proved that pH would affect the growth of blue algae when pH was 5.5, 6.0 and 6.5, and algae would die when pH was 5.5 and 6.0. Yuan Lina[8] concluded that low pH was detrimental to algae. Zhao Na[38] studied the influence of different pH conditions on the growth of Chlorella and Scenedesmus obliquus, and revealed that Chlorella grew best at the pH of 7.0 and Scenedesmus obliquus grew best at the pH of 9.0. Liu Shufeng *et al.* [39] proved that the pH value and the number of algae correlated with each other and ΔpH reached the maximum value at the density of 105 – 106. Ouyang Zhenrong[12] concluded that Chlorella can grow normally at the between pH 6.5 and 9.0 and grew best at the pH of 7.0.

3.5 Other environmental factors Temperature, sunshine, nutrient salt, and pH are major factors influencing the growth of algae. Besides, aerated methods, hydropower and microelements would affect algae[40 – 44]. Aerated air can change the constituents of O_2 and CO_2 in the water and affect the pH in the water. Meanwhile, stirring water can improve the transmission of oxygen and intensify the effects of aerated air on algae[45]. Wang Yunzhong *et al.* [46] concluded that water circle has distinct influences on algae growth and replacement of advantageous species. Water cycle and soil cycle inhibit the growth of algae, and within 49 days, water cycle and soil cycle reduced algae cell amount by 41% and 91% respectively. Meanwhile, mixing is one of the major physical factors which would affect "water – sediment" interface[47]. Besides, mixing would make the particles float. The quicker the disturbance is, the greater the energy released from the sediment.

4 Conclusions

Algae is the foundation of biomass in marine ecological system and the material cycle and energy movement in the entire ecological system. Suitable algae structure not only increase the oxygen amount in the water, but also can form efficient food chain as a kind of food source for aquatic animals so as to improve water environment. Therefore, adjustment of environmental factors can restrain the growth of algae. Current study often focus on influences of sunshine, temperature, nutrient salt and pH on algae, while environment influences algae in many ways. Therefore, it is necessary to study the combined influences of sunshine, temperature, nitrogen, phosphorus, and pH on the growth of algae, and adjust the group structure of algae in waters, which will be the focus for future study.

References

[1] MEI H, ZHAO XF, GUO B, *et al.* Advances in freshwater algal biodiversity in China[J]. Ecologic Science, 2003, 22(4): 356 – 359. (in Chinese).
[2] Rameshprabu Ramaraj, David D-W. Tsai, Paris Honglay Chen. Algae growth in natural water resources[J]. Journal of Soil and Water Conservation, 2010, 42(4): 439 – 450.
[3] WANG L, MIN M, LI YC, *et al.* Cultivation of green algae *Chlorella* sp. in different wastewaters from municipal wastewater treatment plant[J]. Applied Biochemistry and Biotechnology, 2010, 162(4): 1174 – 1186.
[4] JIA Y. Study on the growth, nitrogen and phosphorus removal characteristics of *Chlorella vulgaris* in source separated urine[D]. Beijing: Tsinghua University, 2011: 5 – 10. (in Chinese).
[5] ZHU MY, ZHU GW, ZHAO LL, *et al.* Influence of algal bloom degradation on nutrient release at the sediment-water interface in Lake Taihu, China

[J]. Environmental Science and Pollution Research, 2013, 20(3): 1803–1811.

[6] SHEN ZM, ZHANG T, MA J, *et al*. Study of effects of eutrophication and temperature on algal growth in Taihu Lake[J]. Environmental Monitoring and Forewarning, 2011, 3(2): 1–4. (in Chinese).

[7] CHEN MJ, LI J, DAI X. Effect of phosphorus and temperature on chlorophyll a contents and cell sizes of *Scenedesmus obliquus* and *Microcystis aeruginosa*[J]. Limnology, 2011, 12(2): 187–192.

[8] YUAN LN, SONG W, XIAO L, *et al*. The overall orthogonal design study of multifactor interaction on the growth of *Microcystis aeruginosa* in the presence of adnascent *Pseudomonas* sp. [J]. Journal of Nanjing University, 2008, 44(4): 408–414. (in Chinese).

[9] CHAO JY, YAN RR, ZHANG YM. Optimal growth of and competition between *Microcystis aeruginosa* and *Scenedesmus obliquus* related to temperature [J]. Journal of Ecology and Rural Environment, 2011, 27(2): 53–57. (in Chinese).

[10] ZHU W, WAN L, ZHAO LF. Interspecies competition rule of algae under different temperature and nutrient concentration condition[J]. Ecology and Environmnet, 2008, 17(1): 6–11. (in Chinese).

[11] Alessandro A. Casazza, Erika Y. Ortiz, Patrizia Perego, *et al*. Effect of temperature and nitrogen concentration on the growth and lipid content of *Nannochloropsis oculata* and *Chlorella vulgaris* for biodiesel production[J]. Chemical Engineering and Processing: Process Intensification, 2009, 48(6): 1146–1151.

[12] OUYANG ZR, WEN XB, GENG YH, *et al*. The effects of light intensities, temperatures, pH and salinities on photosynthesis of chlorella[J]. Journal of Wuhan Botanical Research, 2010, 28(1): 49–55. (in Chinese).

[13] WANG ZH, YUAN ML, LIANG Y, *et al*. Effects of temperature and organic and inorganic nutrients on the growth of *Chattonella marina* (Raphidophyceae) from the Daya Bay, South China Sea[J]. Acta Oceanologica Sinica, 2011, 30(3): 124–131.

[14] GUAN D, REN YB, LI J. Effect of environmental factors on harmful algal blooms[J]. Environmental Science and Management, 2011, 36(8): 55–59, 68. (in Chinese).

[15] Marcin W. Wojewodzic, Marcia Kyle, James J. Elser, *et al*. Joint effect of phosphorus limitation and temperature on alkaline phosphatase activity and somatic growth in *Daphnia magna*[J]. Oecologia, 2011, 165: 837–846.

[16] Bojan Tamburic, Fessehaye W. Zemichael, Geoffrey C. Maitland, *et al*. Parameters affecting the growth and hydrogen production of the green alga *Chlamydomonas reinhardtii*[J]. International Journal of Hydrogen Energy, 2011, 36(13): 7872–7876.

[17] T. Y. Yeh, T. Y. Ke, Y. L. Lin. Algal growth control within natural water purification systems: Macrophyte light shading effects[J]. Water Air Soil Pollut, 2011, 214: 575–586.

[18] LIU CG, JIN XC, QIU JQ, *et al*. Influence of interaction of light and phosphorus on growth of two species of algae in freshwaters[J]. China Environmental Science, 2005, 25(1): 32–36. (in Chinese).

[19] GUO YQ. The influencing study of environmental factors on freshwater algae growth in Yellow River[D]. Inner Mongolia: Inner Mongolia University of Science & Technology, 2010: 31–39. (in Chinese).

[20] ZHAI SJ, YANG LY, HU WP. Observations of atmospheric nitrogen and phosphorus deposition during the period of algal bloom formation in Northern Lake Taihu, China[J]. Environmental management, 2009, 44(3): 542–551.

[21] R. Jan Stevenson, Brian J. Bennett, Donielle N. Jordan, *et al*. Phosphorus regulates stream injury by filamentous green algae, DO, and pH with thresholds in responses[J]. Hydrobiologia, 2012, 695: 25–42.

[22] ZHANG JY, NI WM, LUO Y, *et al*. Response of freshwater algae to water quality in Qinshan Lake within Taihu Watershed, China[J]. Physics and Chemistry of the Earth, 2011, 36(9): 360–365.

[23] ZHANG QT, HU GK. Effect of nitrogen to phosphorus ratios on cell proliferation in marine micro algae[J]. Chinese Journal of Oceanology and Limnology, 2011, 29(4): 739–745.

[24] ZHANG QT, WANG XH, LIN C, *et al*. Effects of different nitrogen on proliferation of *Microcystis aeruginosa*[J]. Reservoir Fisheries, 2011(4): 115–120. (in Chinese).

[25] ZHANG QC, YU RC, ZHOU MJ, *et al*. Effects of different phosphorus substrates on growth and toxin generation of *Alexandrium minutum*[J]. Oceanologia Et Limnologia Sinica, 2005(5): 465–474. (in Chinese).

[26] DING JB. Study on the impact of main nutrients as Ca, Mg on grwoth of *Microcystis aeruginosa*[D]. Jiangxi: Nanchang University, 2011: 27–29. (in Chinese).

[27] QIAN SQ, KONG FX, ZHANG M, *et al*. Utilization of dissolved organic phosphorus and the growth of *Microcystis aeruginosa* and *Chlorella pyrenoidosa*[J]. Journal of Lake Science, 2010, 22(3): 411–415. (in Chinese).

[28] XU H, ZHU GW, QIN BQ, *et al*. Influence of nitrogen-phosphorus ratio on dominance of bloom-forming cyanobacteria (*Microcystis aeruginosa*) [J]. China Environmental Science, 2011, 31(10): 1676–1683. (in Chinese).

[29] ZHENG XY, GU YJ, JIN Y. Study on the growth of *Scenedesmus quadricauda* under different nutrients[J]. Ecology and Environmental Sciences, 2010, 19(11): 2663–2668. (in Chinese).

[30] KONG Y, XU XY, ZHU L, *et al*. Control of the harmful alga *Microcystis aeruginosa* and absorption of nitrogen and phosphorus by *Candida utilis* [J]. Applied Biochemistry and Biotechnology, 2013, 169(1): 88–99.

[31] Suneerat Ruangsomboon, Monthon Ganmanee, Sakchai Choochote. Effects of different nitrogen, phosphorus, and iron concentrations and salinity on lipid production in newly isolated strain of the tropical green microalga, *Scenedesmus dimorphus* KMITL[J]. Journal of Applied Phycology, 2012.

[32] MENG SL, QIU LP, HU GD, *et al*. Effect of nitrogen and phosphorus ratios on growth and competition of two blue-green algae[J]. Journal of Agro-Environment Science (J. Agro-Environ. Sci.), 2012, 31(7): 1438–1444. (in Chinese).

[33] Sebnem Aslan, Ilgi Karapinar Kapdan. Batch kinetics of nitrogen and phosphorus removal from synthetic wastewater by algae[J]. Ecological Engineering, 2006, 28(1): 64–70.

[34] DONG J, LI DP, TAO Y, *et al*. Variation of algal-bacterial community under nitrogen-phosphorus stress[J]. Environmental Science & Technology, 2012, 35(12): 40–45, 55. (in Chinese).

[35] S. C. Agrawal. Factors controlling induction of reproduction in algae-review: The text[J]. Folia Microbiol, 2012, 57(5): 387–407.

[36] WANG ZH, CUI FY, AN Q, *et al*. Study on influence of pH on the advance of eutrophication in reservoir[J]. Water & Wastewater Engineering, 2004, 30(5): 37–41. (in Chinese).

[37] WANG X, HAO CB, ZHANG F, *et al*. Inhibition of the growth of two blue-green algae species (*Microsystis aruginosa* and *Anabaena spiroides*) by acidification treatments using carbon dioxide[J]. Bioresource Technology, 2011, 102(10): 5742–5748.

[38] ZHAO N, FENG MF, ZHU L. Toxic effects of chromium(Cr^{6+}) on *Chlorella vulgaris* and *Scenedesmus obliquus* at different pH[J]. Journal of Southeast University (Medical Science Edition), 2010, 29(4): 382–386. (in Chinese).

[39] LIU SF, ZHANG J. Study of algae and it's influencing factors in reservoir [J]. China's Foreign Trade, 2011(12): 418, 431. (in Chinese).

[40] CHEN SG, WANG ZH. Synergistic influence of P and Fe, Mn, Zn on algae growth[J]. Journal of Zhongkai Agrotechnical College, 2012, 25(2): 22–23, 29. (in Chinese).

[41] LONG TY, WU L, MENG GH, *et al*. Numerical simulation for impacts of hydrodynamic conditions on algae growth in Chongqing Section of Jialing River, China[J]. Ecological Modelling, 2011, 222(1): 112–119.

[42] ZHONG YX, TANG ZE, YU GW, *et al*. Growth inhibition of blue-green algae by submerged macrophytes culture solutions with existence of the low level of copper ion[J]. Ecology and Environmnet, 2012, 21(9): 1594–1598. (in Chinese).

[43] JIANG LY, JIANG C, ZHOU W, *et al*. Growth of *Microcystis aeruginosa* under different disturbance[J]. Environmental Chemistry, 2012, 31(2): 216–220. (in Chinese).

[44] LIU J, ZHAO HT, SHENG HJ, *et al*. Effects of Fe^{3+} on growth and calcium/magnesium ions uptakes of three common algae in Taihu Lake[J]. Environmental Science & Technology, 2011, 34(1): 59–64. (in Chinese).

(To page 95)

ternational community increasingly[16]. LEDAPS based on Landsat image uses the radiation change detection method, to obtain forest vegetation information, and provide surface reflectivity products for estimating the carbon stock of a large area of forest ecosystem. With the development of remote sensing technology, the traditional serial LEDAPS preprocessing can not meet the needs of massive remote sensing image. On the basis of in – depth analysis of the principles and features of LEDAPS processing, this paper proposes a parallel computing method for LEDAPS massive image preprocessing based on MPI, considering the problem of time – consuming process of original serial image preprocessing of LEDAPS. The method uses a master-slave mode focuses on the irrelevance between the Landsat data processing, and carries out circular classification of Landsat data, to achieve data parallelization and at the same time achieve the load balancing processing of the task. The experimental results show that when 8 MPI processes run the program, the speedup after load balancing is 7.37. With the increase of computing nodes, the MPI speedup is increased linearly. At the same time, the test results also show that LEDAPS after transformation has good scalability, and is able to minimize the communication between nodes on the basis of load balancing. This parallel method is easy to use, robust and scalable. On the basis of substantially increasing the computing speed and saving the computing time, it realizes the scalability of computing nodes. This will help to apply LEDAPS to the processing of Landsat massive data, form large-scale application of corresponding surface reflectivity products, and accelerate the application of remote sensing technology to forest biomass and carbon stock.

References

[1] XU TS. Study on forest biomass & carbon storage estimation based on remote sensing information[J]. Forest Inventory and Planning, 2008, 33(3): 11 – 13. (in Chinese).

[2] YANG HX, WU B, ZHANG JT, *et al*. Progress of research into carbon fixation and storage of forest ecosystems[J]. Journal of Beijing Normal University(Natural Science), 2005, 41(2): 172 – 176. (in Chinese).

[3] Wolfe R, Masek J, Saleous N, *et al*. LEDAPS: mapping North American disturbance from the Landsat record. In: Geoscience and Remote Sensing Symposium[C]. IGARSS'04 Proceedings. IEEE International, 2004.

[4] LIU HY, LI ES, ZHANG ZH. Study on image parallel OPTA algorithm based on thinning cluster[J]. Engineering of Surveying and Mapping, 2011, 20(20): 35 – 38. (in Chinese).

[5] LU YT. Trend study of extreme large scale parallel computing systems[J]. Computer Engineering & Science, 2012, 34(8): 17 – 23. (in Chinese).

[6] XIAO HL, WANG LS. Investigation on parallel computing algorithm of DNS using pseudo-spectral method based on MPI[J]. Computer Engineering and Applications, 2012, 48(4): 54 – 55. (in Chinese).

[7] HUANG LX, SHAO JL, CUI YL, *et al*. Study on the parallel algorithm for numerical simulation of groundwater based on the MPI[J]. Journal of Anhui Agricultural Sciences, 2012, 40(12): 7356 – 7358. (in Chinese).

[8] Wolfe R, Hall F, Goward S *et al*. Assessing North American forest disturbance from the landsat archive[J]. Geoscience and Remote Sensing Symposium, 2007. IGARSS 2007. IEEE International, 2007, 5294 – 5297.

[9] LI AN, JIANG JG, BIAN JH, *et al*. Experiment and accuracy analysis of automated registration and orthorectification for Landsatlike images based on AROP[J]. Remote Sensing Technology and Application, 2012, 27(1): 23 – 32. (in Chinese).

[10] JU J, Roy D P, Vermote E, *et al*. Continental-scale validation of MODIS-based and LEDAPS Landsat ETM$^+$ atmospheric correction methods[J]. Remote Sensing of Environment. 2012(122): 175 – 184.

[11] Jeffrey G. Masek, Eric F. Vermote, Nazmi E. Saleous *et al*. A Landsat surface reflectance data set for North America, 1990 – 2000[J]. Geoscience and Remote Sensing Letters, 2006, 3(1): 68 – 72.

[12] ZHANG LB, CHI XB, MO ZY. Introduction to parallel computing[M]. Beijing: Tsinghua University Press, 2006. (in Chinese).

[13] WANG W, ZHANG JM. Design and implementation of MPI parallel computing system based on tree structure[J]. Application of Electronic Technique, 2011, 37(12): 126 – 129. (in Chinese).

[14] CHEN CP. The parallel technologies (PaCT – 2003)[C]. Nizhni Novgorod, Russia. 2003.

[15] WANG Y, FAN WY, YANG AL. The application of 6S models for radiative transfer for correcting remote sensing image in Harbin City[J]. Geomatics & Spatial Information Technology, 2008, 31(2): 16 – 19. (in Chinese).

[16] WANG CM, WANG RN, LIN ZL. Carbon sequestration estimation by different tree species and reforestation types in forest ecosystem[J]. Ecology and Environmental Sciences, 2010, 19(10): 2501 – 2505. (in Chinese).

(From page 89)

[45] LUO GY, ZHU L, JI TJ, *et al*. Effects of different P concentration and aeration parttens on growth of algae in freshwaters [J]. Journal of Chongqing University(Natural Science Edition), 2007, 30(2): 86 – 88, 106. (in Chinese).

[46] WANG YZ, YANG CJ, CHEN XD, *et al*. Effects of different water dynamical condition on algae succession in eutrophication process of landscaping water body[J]. The Administration and Technique, 2011, 23(2): 23 – 27. (in Chinese).

[47] DONG LL. The effect of submerged macrophytes together with sediments on the circulation of phosphorus of eutrophic lakes[D]. Tianjin: Tianjin University, 2007: 12 – 16. (in Chinese).