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SHORT COMMUNICATION

Photosynthesis of Periphyton and Diffusion Process as Source of Oxygen in Rich-Riffle Upstream Waters

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Most of dissolved oxygen content in stream or river water is obtained from the process of photosynthesis and diffusion. Photosynthesis process in running water is performed by autotrophic organisms, especially community of attached micro-algae or periphytic micro-algae that live attached to stone or other substrates, while intensive diffusion process occurred as water flows. Rich riffle upstream waters are characterized by stony bottom and high current. The role of the periphyton photosynthesis result and diffusion process along the water current was examined by this research. A field experimental observation was carried out at the upstream of Cisadane River (600 m above water sea level) with two different natural light conditions, the light or exposed (24 630-104 240 Lux) and shadowy (11 120-65 300 Lux) conditions. The actual dissolved oxygen contents in the area with the two conditions are relatively similar; 7.3 (light) and 7.0 mg L^{-1} (shadowy). Oxygen supports were significantly different at the light and shadowy conditions, whether from diffusion process 71.71 and 79.37%, respectively, or from periphyton photosynthesis, 21.73 and 15.30%, respectively. The compositions of periphytons living in the two conditions were similar; mostly composed by group of Diatom, with the same dominant species of *Thalassiothrix* sp. The difference in periphyton growth was shown by its density. In the light condition, the Diatom tends to grow at higher density in comparison to the shadowy condition. The role of periphyton to support oxygen in upstream waters is light dependent. The higher the light intensity (photosynthetic active radiation ranged), the higher the support of oxygen will be.

Key words: diffusion, oxygen support, periphyton, upstream waters

Sebagian besar kandungan oksigen terlarut di sungai berasal dari proses fotosintesis dan difusi. Proses fotosintesis di perairan mengalir dilakukan oleh organisme autotrof, khususnya komunitas mikroalga perifitik yang hidup menempel pada batuan atau substrat lainnya, dan proses difusi intensif yang berlangsung bersamaan dengan aliran air. Sungai bagian hulu dicirikan dengan dasar berbatu dan berarus deras. Penelitian ini dilakukan untuk mengkaji peran oksigen hasil fotosintesis oleh perifiton dan hasil proses difusi di sungai. Pengamatan eksperimental lapangan dilakukan di hulu sungai Cisadane (600 m di atas permukaan laut) dengan dua kondisi cahaya alami berbeda, yaitu terpapar cahaya atau terang (24 630-104 240 Lux) dan terlindung atau teduh (11 120-65 300 Lux). Kedua kondisi cahaya tersebut (terang dan teduh), secara berturut-turut, memiliki kandungan oksigen terlarut aktual yang relatif sama, yaitu 7.3 dan 7.0 mg L^{-1}. Sokongan oksigen dari proses difusi pada kondisi terang (71.71%) dan teduh (79.37%), secara signifikan berbeda dari hasil fotosintesis perifiton pada kedua kondisi, terang (21.73%) dan teduh (15.30%). Komunitas perifiton pada kedua kondisi cahaya didominasi oleh kelompok yang sama, yaitu Diatom dengan spesies dominan *Thalassiothrix* sp. Perbedaan pertumbuhan perifiton ditunjukkan oleh kepadatannya. Kondisi yang terang mendukung pertumbuhan Diatom untuk mencapai kepadatan yang lebih tinggi dari kondisi teduh. Peran perifiton dalam menyokong oksigen di hulu sungai bergantung kepada cahaya. Semakin tinggi intensitas cahaya (dalam kisaran radiasi untuk aktivitas fotosintesis), maka akan semakin tinggi sokongan oksigen yang dihasilkan.

Kata kunci: difusi, hulu sungai, perifiton, sokongan oksigen

Oxygen is an essential element for living, both in terrestrial and aquatic ecosystems. Dissolved oxygen in aquatic ecosystem is very important to support ecological processes within, such as decomposition and respiration.

The variation of oxygen content in water depends on temperature, salinity, water turbulence, and atmospheric pressure. The higher the water temperature and altitude, the lower the atmospheric pressure and dissolved oxygen in the water will be. The dissolved oxygen content in water also depends on mixing, turbulence; photosynthesis, respiration, and decomposition process; and pollution inflow.

The source of dissolved oxygen in running water (lotic) water is influenced by atmospheric diffusion and autotrophic photosynthesis. The atmospheric oxygen diffusion is directed by agitation or turbulence of water mass caused by current or water fall. The liquid film transfer coefficient for oxygen expressed per unit volume of water is termed as the reaeration coefficient, k (d-1). The magnitude of k is importantly influenced by internal turbulence, which acts to reduce the thickness of the diffusional layer. Surface turbulence of most streams is primarily by flow-induced turbulence (Gelda *et al*. 1996). In fact, the process of

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oxygen diffusion from the atmosphere is time consuming, even in a high turbulence condition. As a consequence, the autotrophic photosynthesis plays a very important role as oxygen source in running water system, which is controlled by nutrients, temperature, light, and flow (Uehlinger *et al*. 2000). Therefore, periphyton and phytoplankton community could play roles as autotroph in supporting oxygen of lotic water through photosynthesis process.

This project is a preliminary research to compare oxygen from photosynthesis by autotrophic organism (periphyton and phytoplankton) and atmospheric diffusion, in running water system. The periphyton community was grown on artificial substrates exposed to direct solar radiation (light condition) and indirect solar radiation (shadowy condition).

The field observation was carried out in Cisadane River, 6°32'59"S and 106°41'23"E, Ciampea Udik, Tenjolaya, West Bogor District, West Java. The research was prepared as a field experimental observation in simple random design with solar radiation exposure as treatment factor. This research consists of two parts, pre-observation and main research. There were several supporting data, comprising of aquatic physical, chemical, and biological measurement.

The aim of pre-observation was to determine the appropriate artificial substrate in 'nature-like' growth composition of periphyton. The materials used as artificial substrates were pieces of PVC, plastic rope, glass, and glass fiber, each sized 5x1 cm^2. Substrates were exposed to experimental conditions for fourteen days to grow the community of periphyton. The artificial substrate with sufficient density of periphyton will be used in main research.

Illumination condition was considered as major factor in selection of observation site. Bright illumination sites were located under 24 630-114 500 Lux of light intensity, and dark illumination sites were located under 11 120-98 360 Lux. The other factors are depth and current condition which should be assumed as homogeneous. Based on current condition, the observation sites were categorized as middle velocity current (Janauer *et al*. 2010).

Pre-observation showed that plastic rope was colonised by periphyton in similar composition to the natural condition. The community of periphyton on the plastic rope was dominated by diatoms comprising of *Thallasiothrix, Melosira, Stauroneis,* and *Navicula* with total density of 2160 ind cm^{-2} at the light site, and 1560 ind cm^{-2} at the shadowy site. Meanwhile, the natural periphyton consists of *Thallasiothrix, Melosira, Stauroneis,* and *Navicula*. By this means, plastic rope was used as artificial substrate in the main research.

The main research was conducted to determine the oxygen support from photosynthesis and diffusion process into running water ecosystem. Modified Winkler method was used to ascertain oxygen content as the result of net primary production (NPP) through photosynthesis. Furthermore, the values of actual oxygen, saturated oxygen, and oxygen reaeration coefficient were used to determine the value of oxygen from diffusion process (O'Connor and Dobbins 1958).

Photosynthetic oxygen content or NPP was produced by periphyton grown on selected artificial substrate. NPP was measured as photosynthetic oxygen in four hours period of incubation. Selected substrates were placed in light and dark incubation bottles that were tied to holders (Fig 1). The constructions were located at light site (Station 1) and shadowy site (Station 2) for observation.

Photosynthesis is not only performed by periphyton, but also phytoplankton. Unfiltered water samples were placed in the dark and light incubation bottles to determine the photosynthetic oxygen of the phytoplankton.

The content of dissolved oxygen from atmospheric diffusion (D) was calculated as the result of multiplication of re-aeration coefficient (k) and the difference between values of saturated and actual oxygen (O'Connor and Dobbins 1958). The value of k is influenced by velocity and depth of water.

D = k (saturation DO -actual DO)

$$k_2(20) = 5{,}34 \frac{U^{0,67}}{H^{1,85}} \quad \text{(Owens } et\ al. \text{ 1964)}$$

Where: U = velocity in average (m s^{-1});
H = depth in average (m).

Re-aeration rate of the actual temperature is formulated by Churchill *et al*. (1962) as:

$$k_2(t°C) = k_2(20°C) \times 1.0238^{(t-20)}$$

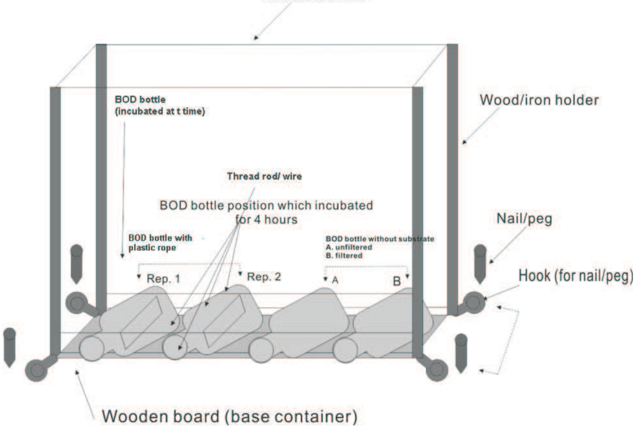

Fig 1 Design of incubation bottles in holder construction.

The approach of re-aeration coefficient determination refers to approximate delta method. The “approximate delta method” is a simple procedure for simultaneous calculation of the stream re-aeration coefficient, primary production rate, and respiration rate from a single-station stream diurnal profile of dissolved oxygen (DO) (McBride and Chapra 2005).

For stream where temperature variability is small, the delta method of Chapra and Di Toro (1991) is useful for scoping DO reaction-rate parameters. This method enables a simple graphic fit to reaeration, production, and respiration rates, and is thus widely used for preliminary interpretation of diel DO studies. This simplicity, however, comes at a price, as the method assumes that reaeration, respiration, and saturation DO concentration are all constant, while production can be described as a simple sinusoidal function for daylight hours (Butcher and Covington 1995).

The observation of periphyton community was performed on scraped sample from 5x1 cm^2 of substrate. The sample was preserved by Lugol's iodine solution (Takano *et al*. 2004), and observed to determine the composition using identification guidelines for freshwater microalgae. The densities were determined using standard equation for periphyton analysis.

The measurement of light intensity, water temperature, current velocity, turbidity, and nutrients (nitrogen from NH_3, NO_2, and NO_3, phospate from PO_4) were held along with the observation of oxygen condition. Besides the nutrients, the other parameters were measured in situ.

Analysis of variance was used to analyze the difference of oxygen support at two sampling sites with different light conditions, and to demonstrate that there is no difference in oxygen support at two sampling sites with different current velocity. The difference between periphyton densities and proportion of oxygen support in both sites were analyzed with t-test.

The rich-riffle upstream water of Cisadane River is characterized by relatively steep sloping riverbank, small to big stones of bottom, and high speed of water current. The ranges of temperature are 23.20-27.2 °C at the light sites (Station 1) and 22.40-24.5 °C at the shadowy sites (Station 2). The light intensity for both light and shadowy conditions ranged around 24 630-104 240 and 11 120-65 300 Lux.

Ciampea River has a high variation of current speed. It is slow at the break of day, which ranged between 0.5-1 ms^{-1}, and higher at noon, of which the condition depends on elevation, depth, and bottom width. High current flow creates a disturbance for periphyton community. Increasing levels of disturbance would systematically remove these rare taxa.

The result showed that periphyton community of the two light conditions was mostly composed of several types of diatoms, which are *Thallasiothrix* sp., *Melosira* sp., *Stauroneis* sp., and *Navicula* sp. (Fig 2). Phytoplankton community consists of *Navicula* sp., *Nitzschia* sp., and *Diatoma* sp. (Fig 3).

The densities of algae at Station 1 were relatively higher than those at Station 2, especially for periphyton community ($P(T<=t)<0.05$) (Fig 2 and Fig 3). It indicates that light intensity has important role in supporting the growth of periphyton.

Algal photosynthesis is conducted at specific range of light intensity (photosynthetic active radiation PAR). The range is species-specific. Each kind of algae will produce organic matter and oxygen as the result of photosynthesis. The product of the photo-synthesis in an algal community will increase with the increase of light intensity. The net primary oxygen production of periphyton was on average 2760.06±1223.75 mg O_2 m^{-2} d^{-1} in 430 L at Station 1 and 2322.70±1133.35 mg O_2 m^{-2} d^{-1} in 430 L at Station 2. The other autotrophic community that contributes in oxygen production aside from periphyton is phytoplankton. However, the

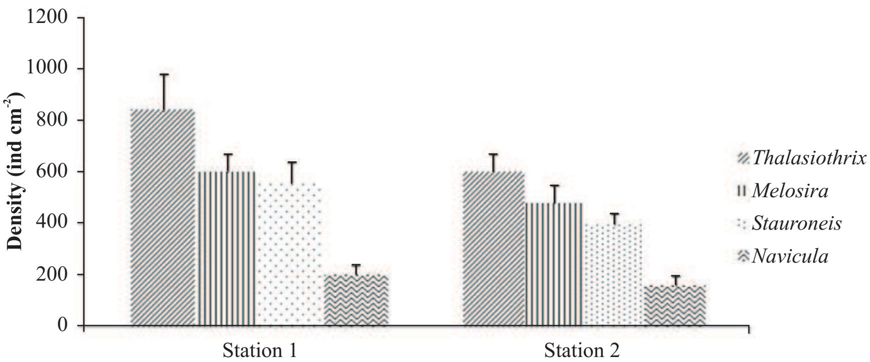

Fig 2 Composition of periphyton on artificial substrate at two sampling sites.

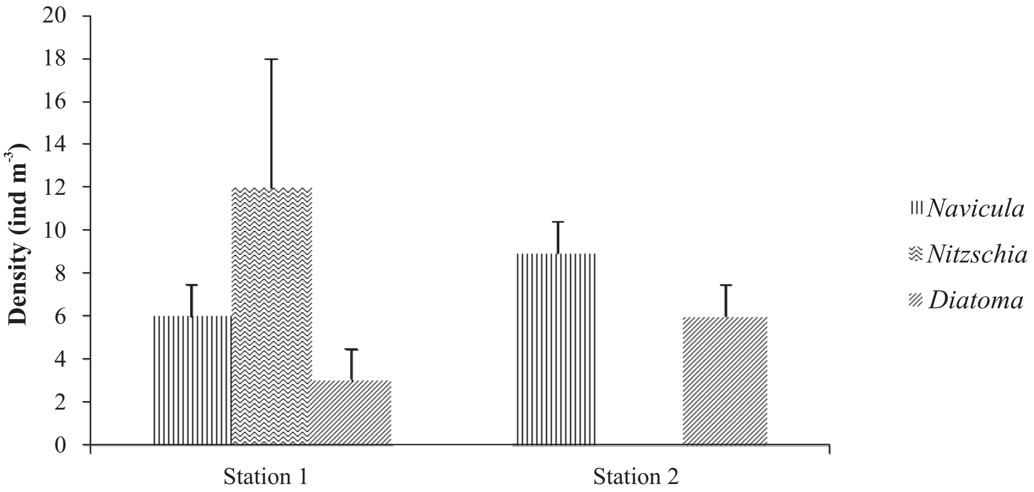

Fig 3 Composition of phytoplankton on artificial substrate at two sampling sites.

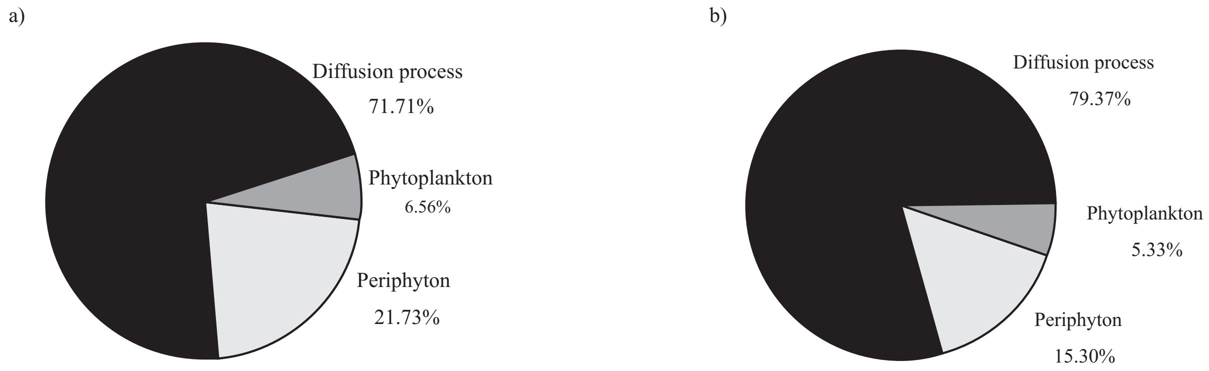

Fig 4 Proportion of oxygen support by photosynthetic and diffusion process at: a) Station 1 and b) Station 2, at lotic system.

contributions by phytoplankton were relatively low, 833.40±321.19 mg O_2 d^{-1} in 430 L at Station 1 and 809.22±340.33 mg O_2 d^{-1} in 430 L at Station 2.

Rich riffle river water create water mass turbulence that generate oxygen content through diffusion process. The oxygen support by diffusion process was calculated using the D value, which was assessed purely by physical process. In this observation, oxygen support from diffusion process was 9106.75±1665.18 mg O_2 d^{-1} in 430 L for Station 1 and 12 050.46±1905.01 mg O_2 d^{-1} in 430 L for Station 2.

Based on those results, it is shown that oxygen support at both light and shadowy conditions from periphyton photosynthesis were 21.73 and 15.30%, and from diffusion process was 71.71 and 79.37%, respectively. These values indicated that diffusion gave higher proportion of oxygen support than photosynthesis ($P(T<=t)<0.05$) in lotic system at the bright illumination site, and *vice versa* (Fig 4).

Autotrophic photosynthesis process of aquatic ecosystem is highly influenced by light intensity in water column. On the other hand, light condition in shallow-river is relatively similar at the surface and at the bottom. These conditions are suitable for algae as the major component of micro-algae community. In a shallow stream, periphyton plays more important roles than plankton in utilization of nutrients and in biomass and oxygen production (Flipo *et al*. 2004; Lutscher *et al*. 2007). Gjerløv and Richardson's (2010) study on the light reduction experiment resulted in a significant reduction of oxygen production when streams were shaded in contrast to their full exposure to sunlight. The biofilm (periphyton) biomass production was also lower under shaded conditions. As a consequence, photosynthesis will proceed as effectively at the bottom of the river, performed by periphytic algae, especially diatoms.

The 14 days exposure of artificial substrates shows a relatively great amount of oxygen for a short diatom natural growth period. It is supposed that in natural substrates, the photosynthesis process by the attached algae could supply higher amount of oxygen to the water column of shallow-river. In certain conditions, physical processes give low oxygen input to the river, as a consequence, oxygen source is mostly emanating from biological process (Nakova *et al*. 2009).

On the other hand, the gradient of fast-flowing rivers running from the mountainous areas to lowland rivers has a large influence towards the diatom assemblages. The influence is rather complex, because variables such as slope, elevation, concentration of nutrients, land-use, and temperature are correlated to one another and these environmental factors determine the diatoms' distribution and composition patterns (Potapova and Charles 2002; Mendes *et al*. 2009). Furthermore, the decrease in the number and varieties of species along the disturbance may have been due to the loss of rare taxa or loss of habitat. Physical and chemical modifications in the habitat of benthic diatoms produced changes in the assemblage. Benthic diatoms' density decreased immediately after the dredging and other physical disturbances (Luttenton and Baisden 2006; Licursi and Gómez 2009). The interference of structuring diatom assemblages will reduce the photosynthesis intensity, and reduce the oxygen production.

Aeration process into water body is one a characteristic of gas concentration fluctuation in water mass. The process occurred when the kinetic energy of turbulence is strong enough to ward off surface tension and gravitation. The water capacity to absorb gas depends on temperature and atmospheric tension. At certain time, water will reach at a saturated condition. Saturated condition of dissolved oxygen is reached when the concentration is balance with the atmospheric oxygen concentration, that the diffusion process will no longer take place.

The result showed that both photosynthesis and diffusion processes took place at both sampling sites. The proportions of oxygen between both processes were significant statistically ($P<0.05$). It showed that intensive diffusion process supplied higher dissolved oxygen than the photosynthesis process. The support of oxygen from photosynthesis process tends to increase by the increase of light intensity. It is shown by the relatively high correlation coefficient between oxygen production and light intensity (0.9439) and between periphyton density and light intensity (0.9739).

In certain conditions, oxygen from diffusion is relatively low although the water turbulence is intensive. On the other hand, it supposed that photosynthesis by attached algae in natural substrates could support higher amount of oxygen to the water column of shallow-river.

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REFERENCES

Butcher JB, Covington S. 1995. Dissolved-oxygen analysis with temperature dependence. J Environ Eng. 121(10):756-759.

Churchill MA, Elmore HL, Buckingham RA. 1962. The prediction of stream reaeration rates. ASCE J Sanit Eng Div. 88(SA4):1-46.

Chapra SC, Di Toro DM. 1991. Delta Method for estimating primary production, respiration, and aeration in stream. J Environ Eng. 117:640-655.

Flipo N, Even S, Poulin M, Tusseau-Vuillemin M, Ameziane T, Dauta A. 2004. Biogeochemical modelling at the river scale: plankton and periphyton dynamics Grand Morin case study, France. Ecol Model. 176:333-347. doi:10.1016/j.ecolmodel.2004.01.012.

Gelda RK, Auer MT, Effler SW, Chapra SC, Storey ML. 1996. Determination of reaeration coefficients: whole lake approach. J Environ Eng. 122(4):269-275.

Gjerløv C, Richardson JS. 2010. Experimental increases and reductions of light to streams: effects on periphyton and macroinvertebrate assemblages in a coniferous forest landscape. Hydrobiologia. 652:195-206. doi:10.1007/s10750-010-0331-7.

Janauer GA, Schmidt-Mumm U, Shmidt B. 2010. Aquatic macrophytes and water current velocity in the Danube River. Ecol Eng. 36:1138-1145. doi:10.1016/j.ecoleng.2010.05.002.

Licursi M, Gómez N. 2009. Effects of dredging on benthic diatom assemblages in a lowland stream. J Environ Manage. 90(2):973-982. doi:10.1016/j.jenvman.2008.03.004.

Lutscher F, McCauley E, Lewis MA. 2007. Spatial patterns and coexistence mechanisms in systems with unidirectional flow. Theor Popul Biol. 71:267-277. doi:10.1016/j.tpb.2006.11.006.

Luttenton MR, Baisden C. 2006. The relationships among disturbance, substratum size and periphyton community structure. Hydrobiologia 561:111-117. doi:10.1007/s10750-005-1608-0.

McBride G, Chapra SC. 2005. Rapid calculation of oxygen in streams: approximate delta method. J Environ Eng. 131(3):336-342. doi:10.1061/(ASCE)0733-9372(2005)131:3(336).

Mendes S, Fernández-Gómez MJ, Resende P, Pereira MJ, Galindo-Villardón MJ, Azeiteiro UM. 2009. Spatio-temporal structure of diatom assemblages in a temperate estuary. A STATICO analysis. Estuar Coast Shelf Sci. 84:637-64. doi:10.1016/j.ecss.2009.08.003.

Nakova E, Linnebank FE, Bredeweg B, Salles P, Uzunov Y. 2009. The river Mesta case study: A qualitative model of dissolved oxygen in aquatic ecosystems. Ecol Inform. 4:339-357. doi:10.1016/j.ecoinf.2009.09.015.

Owens M, Edwards RW, Gibbs JW. 1964. Some reaeration studies in streams. Int J Air Water Pollut. 8:469-486.

O'Connor DJ, Dobbins WE. 1958. Mechanisms of reaeration in natural streams. Transactions of ASCE. 123:641-684.

Potapova MG, Charles DF. 2002. Benthic diatoms in USA rivers: distributions along spatial and environmental gradients. J Biogeogr. 29:167-187.

Takano K, Igarashi S, Hino S. 2004. Seasonal changes in silicon content of diatoms estimated from the ratio of particulate silicon to diatom volume under silicon sufficiency in diatom-rich Lake Barato. Jap J Limnol. 5(2):115-120. doi:10.1007/s10201-004-0117-6.

Uehlinger U, Konig C, Reichert P. 2000. Variability of photosynthesis-irradiance curves and ecosystem respiration in a small river. Freshw Biol. 44:493-507.