Water quality changes in floodplain lakes due to the Amazon River flood pulse: Lago Grande de Curuaí (Pará)

Affonso, AG., Barbosa, C. and Novo, EMLM.*

Instituto Nacional de Pesquisas Espaciais – INPE, Divisão de Sensoriamento Remoto,
Av. dos Astronautas, 1758, CEP 12227-010, São José dos Campos, SP, Brazil
*e-mail: affonso@dsr.inpe.br

Received June 4, 2010 – Accepted August 27, 2010 – Distributed August 31, 2011
(With 4 figures)

Abstract

Assurance of water quality for human consumption is essential for public health policies. In the Amazon floodplain, the seasonal water level variation causes periodic flooding of marginal areas that are usually used for settlements, agriculture and livestock. Therefore, the exchange of materials between the terrestrial and aquatic ecosystem affects the proportion of suspended and dissolved components in water and its physical-chemical characteristics, and consequently the quality of the water used by local people. Following this approach, the aim of this study is to evaluate changes in water quality in Lago Grande de Curuaí floodplain, Óbidos, Pará in response to the flood pulse, during one hydrological year from 2003 to 2004, based on water use classes (according to National Water Agency 357/2005 resolution) using chlorophyll-α and dissolved oxygen concentration as parameters and the eutrophication index. Ordinary kriging was applied to interpolate chlorophyll-α and dissolved oxygen and to predict values at non sampled locations. Each location was then classified according to water use acceptable parameters and to Carlson Trophic State Index modified by Toledo to map lake water classes and trophic status. The result showed that Lago Grande de Curuaí floodplain is a supereutrophic system, with levels of dissolved oxygen and chlorophyll-α not suitable for human supply during the receding water phase. These areas are located near the riverine communities, which can cause health problems due to the presence of potentially toxic algae. Therefore, monitoring water quality in Amazon lakes is essential to ensure the availability has appropriate quality for human and animal supplies.

Keywords: Amazon várzea, chlorophyll-α, dissolved oxygen, eutrophication index, seasonality.

Mudanças na qualidade da água nos lagos de planície de inundação em função do pulso de inundação do rio Amazonas: lago Grande de Curuaí, Pará

Resumo

A garantia da qualidade da água para consumo humano é essencial para as políticas de saúde pública. Na planície Amazônica a variação sazonal do nível de água provoca inundações periódicas das áreas marginais que são normalmente utilizadas para os assentamentos humanos, a agricultura e a pecuária. Portanto, a troca de materiais entre os ecossistemas terrestres e aquáticos afeta a proporção de componentes em suspensão e dissolvidos na água e suas características físico-químicas, o que, consequentemente, afeta a qualidade da água utilizada pela população local. Seguindo essa abordagem, o objetivo deste trabalho é avaliar as mudanças na qualidade da água na planície de inundação do lago Grande de Curuaí, Óbidos, Pará, em função do pulso de inundação, durante um ano hidrológico de 2003 a 2004, tendo por base tanto as classes de uso da água (de acordo com a Resolução nº 357/2005 da Agência Nacional de Água), usando como parâmetros tanto a concentração de clorofila-α e o oxigênio dissolvido, quanto o índice de eutrofização. Utilizou-se o método de krigagem para interpolar os dados de clorofila-α e de oxigênio dissolvido e inferir os valores em locais não amostrados. Cada região foi então classificada de acordo com parâmetros aceitáveis das classes de uso da água e do índice de estado trófico de Carlson modificado por Toledo para gerar mapas de classes de água e de estado trófico. O resultado mostrou que a planície de inundação do lago Grande de Curuaí é um sistema supereutrófico, com níveis de oxigênio dissolvido e clorofila-α imprópria para o abastecimento humano durante o período de vazante do ciclo hidrológico. A saúde das comunidades ribeirinhas localizadas nas margens da planície está ameaçada pela presença de algas potencialmente tóxicas. Portanto, o monitoramento da qualidade da água em lagos da Amazônia é essencial para garantir a sua disponibilidade com qualidade para o abastecimento humano e de animais.

Palavras-chave: várzea amazônica, clorofila-α, oxigênio dissolvido, índice de eutrofização, sazonalidade.

1. Introduction

Assurance of water quality for human consumption is essential for public health policies. The increasing world population requires more water and therefore its quality and quantity provision is at risk due to constant degradation caused by irrigation, sewage disposal, industrial pollution, among other factors (WHO, 1996). Using aquatic environments for water supply, power generation, irrigation, navigation, aquaculture and recreation requires proper maintenance and monitoring in order to *"ensure the availability of good quality water to current and future generations for their purposes"* according to Law 9433 of January 8, 1997 of the Brazilian National Policy on Water Resources (ANA, 2008).

Water quality monitoring for public supply is based on measuring microbiological, physical and chemical constituents potentially harmful to human health according to standards established by relevant authorities. In Brazil, the CONAMA 357/2005 resolution defined five classes of freshwater quality standard required for their predominant use (Table 1) (ANA, 2008). For each class, the maximum concentration of organic and inorganic material allowed in water and also its physical and chemical properties are defined.

In spite of the clear definition of the parameters used to assess water quality, this quality is easily affected by weather, solar radiation, hydrology, and human activities (Hooda et al., 2000; Tundisi et al., 2004; Whitehead et al., 2009). The dynamic nature of the aquatic systems makes it difficult to distinguish between natural variability and anthropogenic influences (Chipps et al., 2006). This distinction is even more difficult in the Amazon floodplain lakes where the flood pulse controls the ecosystem dynamics.

The Amazon River floodplain, also known as "várzea" is one of the richest wetland systems in the Brazilian Amazon (Goulding et al., 1996; Junk et al., 2000) and has a population of approximately 1.5 million inhabitants, corresponding to 54% of the rural population of Amazonas and Pará states (IBGE, 2000). Public policies carried out in the 1970s aiming to integrate the Amazon region into southeastern Brazil attracted large number of immigrants who were engaged in huge development projects (hydroelectric power plants and highway constructions, mineral exploitation and cattle ranching). These policies changed the use of floodplain resources, originally related to subsistence fishing and small-scale agriculture. In 2008, the total livestock in the lower Amazon basin (from Parintins to Almeirim municipalities) was estimated at 1,390,740 heads, 60% of which were confined to the floodplain and in deforested areas near the Amazon River bank (Barbarisi, 2010).

The seasonal water level variation controls the life in the "várzea". The annual and monomodal variation of the Amazon River water level, is mainly caused by the high abundance and seasonal rain in the Andin region. This leads to an annual average water level amplitude that can reach up to 10 m, which corresponds to 230 days of flooding period (Junk, 1997). This flood pulse causes periodic flooding of marginal areas that are usually used for settlements, agriculture and livestock. The conversion of forest areas into pasture and agricultural areas either in the floodplain or in the Terra Firme forest (upland forest)

Table 1. Freshwater classes and acceptable uses.

Classes	Acceptable uses
Special	Supply for human consumption with disinfection; Preservation of aquatic community natural balance; Conservation of aquatic environments in Conservation Units.
1	Supply for human consumption after simplified treatment; Protection of aquatic communities; Primary contact recreation (swimming); Irrigation of vegetables and fruits that are either raw consumed or grown near the ground; Protection of aquatic communities located at native reserve.
2	Supply for human consumption after conventional treatment; Protection of aquatic communities; Primary contact recreation; Irrigation of vegetables, fruit trees, parks, gardens, sports and recreation fields, in which the public might have direct contact; Aquaculture and fishing activity.
3	Supply for human consumption after conventional or advanced treatment; Irrigation of tree crops, cereals and fodder; Recreational fishing; Secondary contact recreation; Supply for animal consumption.
4	Sailing/navigation; Landscape design.

affects the water flow and the exchange of materials between the terrestrial and aquatic ecosystem, changing the proportion of suspended and dissolved components in water and their physical-chemical characteristics (Melack and Forsberg, 2001; Tundisi et al., 2002). Novo et al. (2006) demonstrated that there is a six-month delay between the maximum water level and the maximum average of chlorophyll-α concentration in floodplain lakes between Parintins and Santarém, i.e. the phytoplankton peak production is achieved when the Amazon pulse recedes and the lakes are enriched by dissolved nutrients but less turbid water due to the sedimentation process. High chlorophyll-α concentrations, above normal levels, were also observed (Barbosa, 2005) suggesting that these lakes might be under severe eutrophication related to cattle ranching and agriculture (McGrath et al., 2007).

Aquatic system eutrophication is caused by increases in nutrient concentration (mainly phosphorus and nitrogen compounds) and/or organic matter in an aquatic ecosystem. This increase can be both natural and human induced (Moss 1988; Wetzel 2001). Various studies have already addressed the problems related to aquatic system eutrophication which impairs its ability to supply both human needs and maintenance of aquatic life (Espíndola et al., 2000; Sampaio et al., 2002; Sotero-Santos et al., 2008; Garcia et al., 2010). Moreover, this phenomenon can cause major functional and compositional shifts in ecosystems (Scheffer et al., 2001; Schindler, 2006) and the increase in diseases in humans and wildlife (Johnson et al., 2010). Furthermore, eutrophication can cause excessive growth of algae which can result in red tide blooms in oceans, and cyanobacterial blooms in freshwater (Landsberg 2002; GEOHAB 2005; Heisler et al., 2008; Richlen et al., 2010). The occurrence of algae and cyanobacteria in water can alter its color, odor and taste and also be a potential source of contamination because of the toxins derived from cyanobacterias. Therefore, the water may become unfeasible for human and animal supply (Pitois et al., 2000; Mankiewicz et al., 2003).

Water quality monitoring of Amazon floodplain lakes is vital for rural inhabitants, locally called “ribeirinhos”, who use the same water as flood cattle and buffalo pasturelands. In spite of the huge water supply in the Amazon, 55.7% of households are not supplied with indoor plumbing, 32.4% of the total water volume distributed is untreated and 92.9% of the municipalities do not have a sewage system (IBGE, 2002). The only prevention provided by the local authorities is the use of a chlorine compound added to the drinking water (Moura, 2007; Renó, 2010).

Taking those facts into account, the aim of this paper is to characterize the water quality of the Lago Grande de Curuaí floodplain-lake system located at Óbidos, Pará over one hydrological year. The parameters used in the characterization were chlorophyll-α and dissolved oxygen concentration, the eutrophication index and the water use classes (according to CONAMA 357/2005 resolution) (MMA, 2005).

2. Material and Methods

2.1. Study area

The study area includes Lago Grande de Curuaí floodplain which is located along the Amazon River near Óbidos city (Brazil), 900 km upstream from the Atlantic Ocean (Figure 1). The Curuaí floodplain is formed by quaternary sandy sediments with more than 30 lakes interconnected with each other and permanently connected to the Amazon River by channels (Moreira-Turcq et al., 2004; Dosseto et al., 2006). Flooding extension can vary from 1,340 to 2,000 km² depending on the water level. The seasonal amplitude can vary from 5 to 7 m and inter-annual variability can be up to 2 m (Figure 2) (Barbosa, 2005). A census conducted in 1996 by Iara Project counted 11,372 residents divided into 33 communities and 1,600 houses (Isaac et al., 2003). Barbosa (2005) noted in 2003 that there were 20,000 inhabitants in 96 communities. Curuaí has a strong fishing (450t of fish was caught in 2003) and ranch tradition (Pinto et al., 2007) with 234,678 cattle heads according to the 2006 census (IBGE, 2006)..

2.2. Field sampling

Chlorophyll-α and dissolved oxygen data were collected at different hydrograph states (receding, low, rising and high water) in the Lago Grande de Curuaí floodplain (Figure 1). Dissolved oxygen was measured using the HORIBA-U10, which has a 0,01 mg/L resolution. Surface water samples were collected, filtered (Whatmann GF/C fiberglass filter (0.5 – 0.7 mm)) and stored in silica gel at 0 °C until further analysis in a laboratory for chlorophyll-α determination using a spectrophotometer (Wetzel and Likens, 1991).

Information on water sampling and analyses protocols can be found in Barbosa (2005). The number of samples varied in different states (Table 2) as the open water extent changed from one state to other. There were two types of sampling station: 1) Complete sample: where both chlorophyll-α and dissolved oxygen were measured (magenta dots in Figure 1), and 2) Incomplete sample: whereas only dissolved oxygen was measured (yellow dots in Figure 1).

2.3. Spatial analysis

In order to characterize the spatial dynamic of water properties, spatial modeling methods were applied to in situ data so as to infer variable values at positions which were not sampled. The first step in the process was to carry out the variogram analysis which describes the spatial structure among samples for each variable in each state of the hydrograph. Based on the variogram parameters, in situ data was then spatially interpolated using the ordinary kriging method (Burrough and McDonnell, 1998).

2.4. Water quality characterization

Water quality was characterized in the different states of the hydrograph according to two approaches. In the first one, dissolved oxygen and chlorophyll-α spatialized data were classified according to CONAMA´s resolution standards (Table 3).

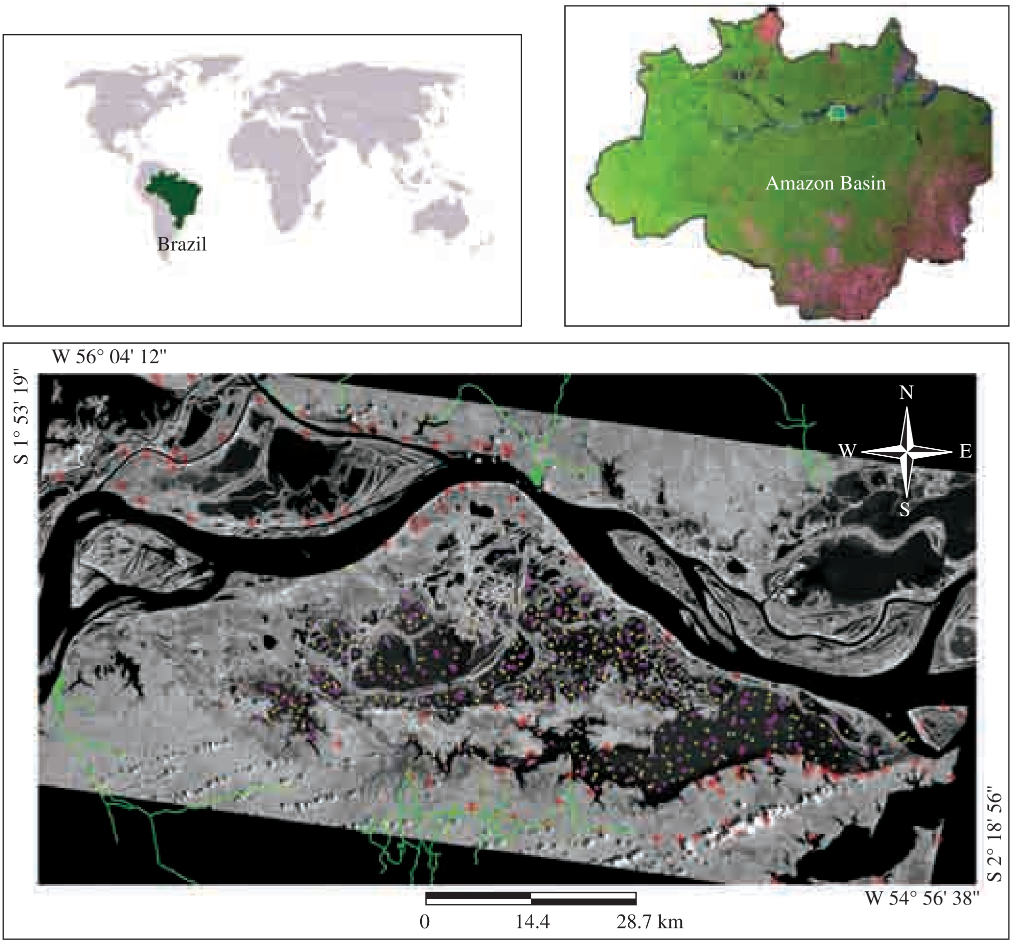

Figure 1. Lago Grande de Curuaí floodplain, with rural communities (red dots), roads (green lines), complete samples (magenta dots) and incomplete samples (yellow dots) sample points collected in different phases of the hydrograph over a TM/Landsat band 4 (10/28/1999). Source: Adapted from Barbosa (2005).

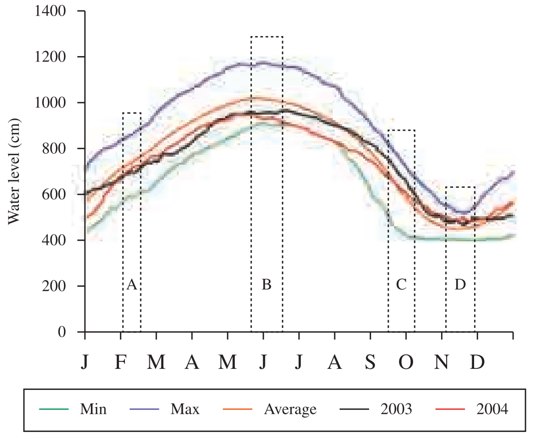

Figure 2. Water level variation of Lago Grande de Curuaí throughout 2003 and 2004 (studied hydrological year) and the minimum, maximum and average water level amplitude from 1993 to 2009. Black dotted boxes indicate the field sampling period where: A, rising water; B, high water; C, receding water; and D, low water.

The dissolved oxygen and chlorophyll-α spatialized data were used to generate a water class map according to Table 3 taking into consideration the highest restriction i.e. if the oxygen concentration was higher than 6 mg/L (Class 1) but the chlorophyll-α was between 10 µg/L to 30 µg/L, then that region was classified as Class 2.

The second approach consisted of using the spatial distribution of chlorophyll-α to compute Carlson's Trophic State Index (TSI) modified by Toledo-Junior et al. (1983) as follows:

$$\mathrm{TSI} = 10 \times \left(6 - \frac{2.64 - 0.695\ln(\mathrm{chl})}{\ln(2)}\right) \quad (1)$$

Where, ln (chl) is neperian logarithm of chlorophyll-α concentration.

The TSI equation (1) was applied to the chlorophyll-α spatialized data and subsequently sliced (the spatialized data was divided into a number of intervals which reflected the range of TSI values) according to trophic level classification system described in Table 4.

Table 2. Number of sample points collected per parameter in different phases of the hydrograph.

Hydrograph phase	Receding water	Low water	Rising water	High water
Parameters/ Date	23/09 to 9/10/03	4/11 to 1/12/03	1/02 to 14/02/04	31/05 to 21/06/04
Dissolved Oxygen	208	202	221	256
Chlorophyll-α	72	73	74	76

Table 3. Water quality appropriate standards (maximum and minimum acceptable concentration values) according to water use classes by CONAMA resolution nº 357/2005.

Variable	Unit	Class 1	Class 2	Class 3	Class 4
Dissolved oxygen	mg/L	>6	>5	>4	>2
Chlorophyll-α	µg/l	<10	10 < 30	30 < 60	>60

Table 4. Trophic State Index classification according to Carlson's Index modified by Toledo-Junior et al. (1983).

Trophic State	TSI
Ultraoligotrophic	≤47
Oligotrophic	47 ≤ 52
Mesotrophic	52 ≤ 59
Eutrophic	59 ≤ 63
Supereutrophic	63 ≤ 67
Hypereutrophic	>67

3. Results

Chlorophyll-α concentrations varied throughout the hydrological year with the lowest average concentration during the low water period (8.16 µg/L) and the highest average during the receding water period (63.9 µg/L), and the minimum value recorded was 0.21 µg/L (flooding season) and the maximum was 337.5 µg/L (receding water period). In relation to dissolved oxygen concentrations, the higher average value was during the high water phase (7.30 mg/L) and the lower occurred at low water phase (4.68 mg/L), and the minimum concentration measured was 2.54 mg/L (high water period) and the maximum was 13.2 mg/L (receding water period).

Water quality for Curuaí floodplain lakes varied through the hydrograph states (Figure 3). During the flood period (rising water) Curuaí floodplain lakes could be used for human supply after simplified treatment (adding a chlorine compound into the water) (Classes 1 and 2) (Table 5). At the high water phase, the lake water can only be used for human supply after a conventional (flocculation, filtration, pH adjustment, disinfection (chlorination) and fluoridation) or advanced treatment (removal and / or inactivation of residual constituents after conventional treatment) (Classes 2 and 3).

However, the receding state is the most critical for water supply especially in the south communities. Because of the high chlorophyll-α concentration (the highest range from 4,15 µg/L to 337,5 µg/L), the water is inappropriate for human, animal supply and even for fishing, recreation and any other activity, for southern communities. During this time of the year, the water can only be used for navigation and landscape design. Finally, in the low water phase the water can be used for human supply only after conventional or advanced treatment (Class 3). We can also observe some patches of Class 4 in the high and low water phase, probably derived from an algae bloom in the region which is used for buffaloes ranching, and therefore not appropriate for human or animal supply.

Figure 4 presents the changes in the trophic state of Curuaí floodplain lakes during the hydrological year. A seasonal variation in the trophic level of the water body can be observed in response to the flood pulse. During the flood (rising water) the lake ranges from oligotrophic to mesotrophic, with some ultraoligotrophic regions. In the high water phase, the large amount of nutrients from the terrestrial environment causes an increase in primary productivity and the lake becomes supereutrophic and even hypereutrophic in some regions. During receding water, the lake becomes hypereutrophic, with high concentrations of chlorophyll-α all over the lake. In low water, the lake becomes supereutrophic in response to the high primary productivity.

4. Discussion

In the hydrological year of 2003 to 2004, Lago Grande de Curuaí floodplain was a supereutrophic system, with levels of dissolved oxygen and chlorophyll-α not suitable for human and animal supply during the receding water period, according to standards established by relevant authorities (MMA, 2005).

Chlorophyll-α and dissolved oxygen concentration have similar dynamics during the hydrological year. At the beginning of the flooding phase, the oxygenated waters from the Amazon River entered the floodplain enriching lake waters. At the same time, a large amount of nutrient input provides an environment for algae bloom in regions far from the turbidity plumes caused by large amounts of

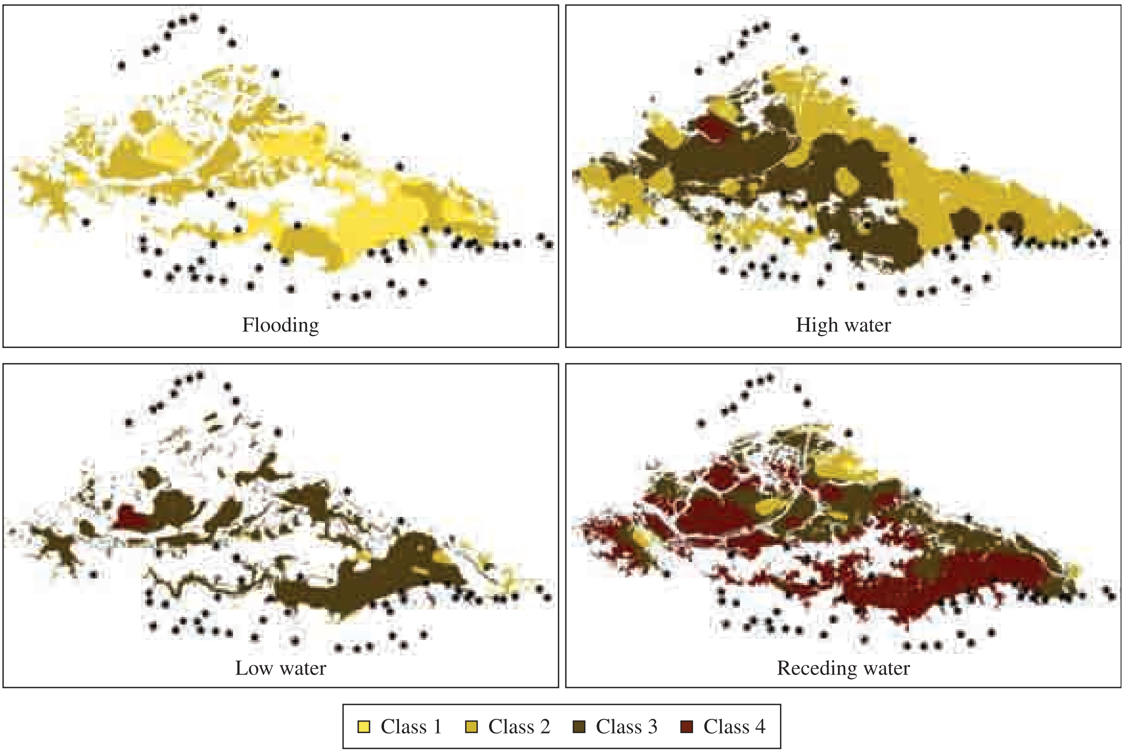

Figure 3. Water classes during the four states of hydrograph and the local communities (black stars).

Table 5. Water classes during the hydrograph and its acceptable uses according to CONAMA 357/2005 resolution.

Classes	States of hydrograph	Acceptable uses
1	Flooding	Supply for human consumption after simplified treatment; Protection of aquatic communities; Primary contact recreation (swimming); Irrigation of vegetables that are eaten raw and fruit that is grown close to the ground; Protection of aquatic communities located at indigenous lands
2	Flooding High water Receding water (patches)	Supply for human consumption after conventional treatment; Protection of aquatic communities; Primary contact recreation; Irrigation of vegetables, fruit trees, parks, gardens, sports and recreation fields, in which the public might have direct contact; Aquaculture and fishing activity
3	High water Low water Receding water	Supply for human consumption after conventional or advanced treatment; Irrigation of tree crops, cereals and fodder; Recreational fishing; Secondary contact recreation; Supply for animal consumption.
4	Receding water High water (patches) Low water (patches)	Sailing/navigation; Landscape design;

suspended inorganic particles. This dynamic can change or restrict the use of water for certain purposes throughout the hydrological year, and therefore affect local communities. The linkage between eutrophication of a water body and harmful algae bloom has been described in detail in the literature (Pitois et al., 2001; Anderson et al., 2002; Granéli et al., 2008; Heisler et al., 2008). The nutrient increase can lead to high levels of phytoplankton biomass, which in turn might decrease its assemblage diversity when the water body becomes more eutrophic, and ultimately will be

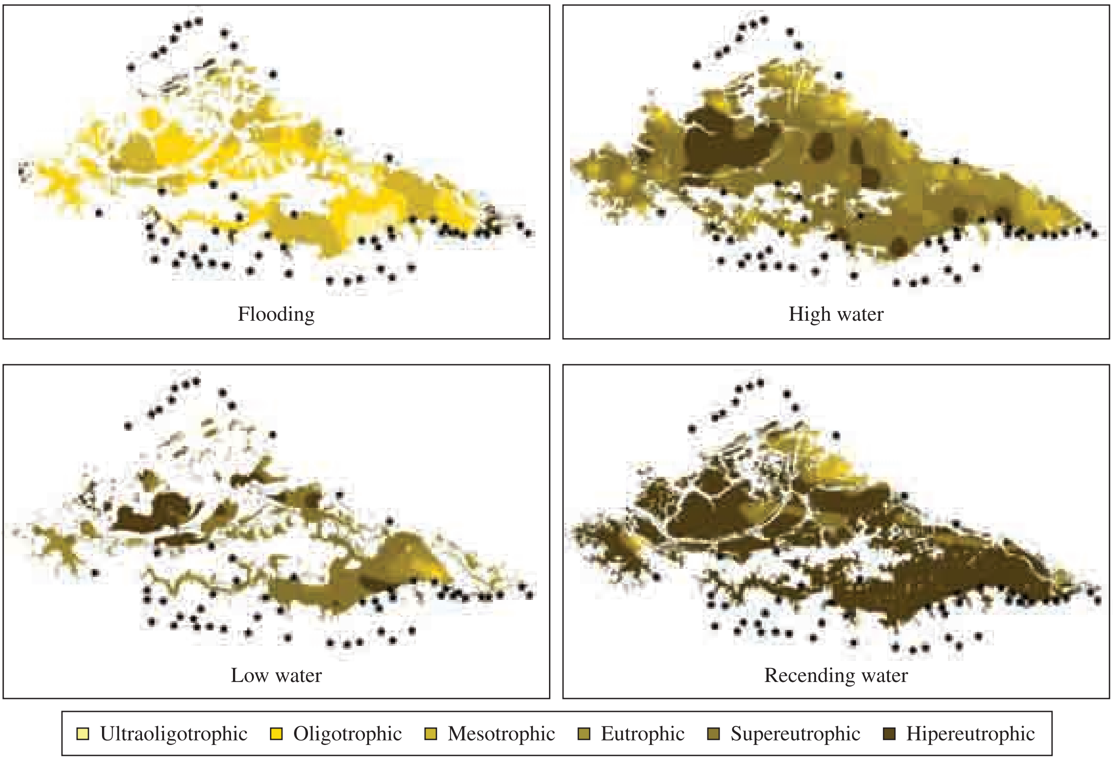

Figure 4. Trophic states during the four states of hydrograph and the local communities (black stars).

dominated by cyanobacteria (Dokulil and Teubner, 2000). Cyanobacteria blooms can cause not only an unpleasant taste and smell in the water, but also may undergo stress releasing toxins (hepatic, neuro and dermatotoxins) (Mankiewwicz et al., 2003). Furthermore these toxins have been responsible for lethal, acute and chronic poisonings of wild/domestic animals and humans in different water bodies all over the world (Carmichael, 2001). Although it had never been described in the literature concerning the phytoplankton communities in Lago Grande de Curuai, a recent characterization in that region detected a 38% relative abundance of cyanobacteria, 38% of Bacillariophyceae and 24% of Chlorophyceae, during the receding water phase in 2009 (Casali et al., in press). Even after the second highest high water period over the last 50 years, in which various municipalities declared an emergency state, because they had already reached the maximum water level quota (CPRM, 2009), Lago Grande de Curuai presented high levels of chlorophyll-α concentrations (ranging from 47 µg/L to 133 µg/L) (Barbarisi, 2010) and a high relative abundance of cyanobacterias (Casali et al., in press). Besides that, Sá et al. (2010) noted an intense proliferation of the genera Anabaena and Microcystis in the left margin of the Tapajos River during a rising water period in 2007. Moreover, Vieira et al. (2005) reported the first bloom of cyanobacteria in a water supply reservoir in the Amazon region in Belém, Pará State. The increase in these algae concentration in Amazon natural water bodies might be a problem for local communities that use this water for human and animal supply, fisheries, and recreation. Silva (2006) showed the relationship between water source for human supply (primarily from rivers and streams) and the prevalence of multiple intestinal parasites in Amazon floodplain communities. Toxic algae blooms are regular and recurrent in the Brazilian water bodies outside the Amazon region (Yunes et al., 2003; Silva et al., 2007; Sotero-Santos et al., 2008; Chaves et al., 2009; Costa et al., 2009; Yunes, 2009), and had already caused the death of 70 chronic renal patients in a hemodialysis clinic in the Caruaru municipality in the State of Pernambuco in 1996 (Azevedo et al., 2002). The incidence of these toxins in reservoirs responsible for the production and distribution of potable water made water agencies around the world adopt improved purification for providing safe drinking water (Hitzfeld et al., 2000; Schmidt et al., 2008). Notwithstanding the limited (one hydrological year) and the large inter-annual variability of the hydrology forcing functions in the region, the results suggest that Lago Grande de Curuaí floodplain water properties are under severe eutrophication and may pose a threat not only to human health, but also to aquatic fauna and flora. It also points out the urgency of a temporal and spatial analysis of phytoplankton communities and water quality monitoring in the Amazon region due to the enormous dependence of the local communities to the natural water supply.

Acknowledgments – The authors thank FAPESP (Fundação de Amparo a Pesquisa do Estado de São Paulo) for funding all fieldwork campaigns (Process 2003/06999-8)

References

Agência Nacional de Águas – ANA, 2008. *Lei 9.433, em 1997, estabelecendo a Política e o Sistema Nacional de Gerenciamento de Recursos Hídricos e a criação da Agência Nacional de Águas*. Available from: <http://www.ana.gov.br/ Institucional/Legislacao/leis/lei9433.pdf>. Access in: maio 2008.

ANDERSON, DM., GLIBERT, PM, and BURKHOLDER, JM., 2002. Harmful Algal Blooms and Eutrophication Nutrient Sources, Composition, and Consequences. *Estuaries*, vol. 25, no. 4B, p. 704-726.

AZEVEDO, SMFO., CARMICHAEL, WW., JOCHIMSEN, EM., RINEHART, KL., LAU, S., SHAW, GR. and EAGLESHAM, GK., 2002. Human intoxication by microcystins during renal dialysis treatment in Caruaru – Brazil. *Toxicology*, vol. 181/182, p. 441-446. http://dx.doi.org/10.1016/S0300-483X(02)00491-2

BARBARISI, BF., 2010. *Integração de imagens MODIS e de dados censitários na avaliação do impacto da pecuária sobre o estado trófico de sistemas aquáticos do baixo amazonas*. São José dos Campos, São Paulo: Instituto Nacional de Pesquisas Espaciais. 150 p. Dissertação de Mestrado em Sensoriamento Remoto.

BARBOSA, CCF., 2005. *Sensoriamento remoto da dinâmica de circulação da água do sistema planície de Curai / rio Amazonas*. São José dos Campos, São Paulo: Instituto Nacional de Pesquisas Espaciais. 255 p. Tese de Doutorado em Sensoriamento Remoto.

BURROUGH, PA. and McDONNELL, RA., 1998. Principles of geographical information systems. New York: Oxford University Press. 334 p.

CASALI, S., BARBARISI, B., RENÓ, V., AFFONSO, AG., BARBOSA, C. and NOVO, EMLM., in press. Temporal and spatial variations of phytoplankton communities in Lower Amazon floodplain lakes. *Hydrobiologia*.

CARMICHAEL, WW., 2001. Health Effects of Toxin-Producing Cyanobacteria: "The CyanoHABs". *Human and Ecological Risk Assessment*, vol. 7, no. 5, p.1393-1407. http://dx.doi.org/10.1080/20018091095087

CHAVES, PF., de La ROCHA, S., Dutra, ATM. and Yunes, J.S., 2009. Ocorrência de cianobactérias produtoras de toxinas no Rio dos Sinos (RS) entre os anos de 2005 e 2008. *Oecologia Brasiliensis*, vol. 13, no. 2, p. 319-328. http://dx.doi.org/10.4257/oeco.2009.1302.07

CHIPPS, SR., HUBBARD, DE., WELIN, KB., HARGERUD, NJ., POWELL, KA., THOMPSON, J. and JOHNSON, T., 2006. Association between wetland disturbance and biological attributes in floodplain wetlands. *Wetlands*, vol. 26, no. 2, p. 497-508.

COSTA, IAS., CUNHA, SRS., PANOSSO, R., ARAÚJO, MFF., MELO, JL. and ESKINAZI-SANT'ANNA, EM., 2009. Dinâmica de cianobactérias em reservatórios eutróficos do semi-árido do Rio Grande do Norte. *Oecologia Brasiliensis*, vol. 13, no. 2, p. 382-401. http://dx.doi.org/10.4257/oeco.2009.1302.11

Companhia de Pesquisa de Recursos Minerais – CPRM, 2009. *Monitoramento Hidrológico, Relatórios de cheia, Boletim n° 23 de 03/07/2009*. 12 p.

DOKULIL, MT. and TEUBNER, K., 2000. Cyanobacterial dominance in lakes. *Hydrobiologia*, vol. 438, no. 1/2, p. 1-12.

DOSSETO, A., BOURDON, B., GAILLARDET, J., ALLÈGRE, CJ. and FILIZOLA, N., 2006. Time scale and conditions of weathering under tropical climate: Study of the Amazon basin with U-series. *Geochimica et Cosmochimica Acta*, vol. 70, no. 1, p. 71-89. http://dx.doi.org/10.1016/j.gca.2005.06.033

ESPÍNDOLA, ELG., MATSUMURA-TUNDISI, T., RIETZLER, AC. and TUNDISI, JG., 2000. Spatial heterogeneity of the Tucuruí reservoir (State of Pará, Amazonia, Brazil) and the distribution of zooplanktonic species. *Brazilian Journal of Biology*, vol. 60, no. 2, p. 179-194.

GARCIA, AC., BARGU, S., DASH, P., RABALAIS, N., SUTOR, M., MORRISON, W. and WALKER, ND., 2010. Evaluating the potential risk of microcystins to blue crab (Callinectes sapidus) fisheries and human health in a eutrophic estuary. *Harmful Algae*, vol. 9, no. 2, p. 134-143. http://dx.doi.org/10.1016/j.hal.2009.08.011

Global Ecology and Oceanography of Harmful Algal Blooms – GEOHAB, 2005. GEOHAB Core Research Project: HABs in Upwelling Systems. In Pitcher, G., MOITA, T., TRAINER, V., KUDELA, R., FIGUEIRAS, P. and PROBYN, T. (Eds). *IOC and SCOR, Paris and Baltimore*. GEOHAB. 82 p.

GOULDING, M., SMITH, NJH. and Mahar, DJ., 1996. *Floods of Fortune*: Ecology and Economy Along the Amazon. New York: Columbia University Press. 193 p.

Granéli, E., Weberg, M. and Salomon, PS., 2008. Harmful algal blooms of allelopathic microalgal species: The role of eutrophication. *Harmful Algae*, vol. 8, no. 1, p. 94-102. http://dx.doi.org/10.1016/j.hal.2008.08.011

HEISLER, J., GLIBERT, PM., BURKHOLDER, JM., Anderson, DM, Cochlan, W., DENNISON, WC., DORTH, Q., GOBLER, CJ., HEIL, CA., HUMPHRIES, E., LEWITUS, A., MAGNIEN, R., MARSHALL, HG., SELLNER, K., Stockwell, DA., STOECKER, DK., and Suddleson, M., 2008. Eutrophication and harmful algal blooms: A scientific consensus. *Harmful Algae*, vol. 8, no. 1, p. 3-13. http://dx.doi.org/10.1016/j.hal.2008.08.006

HITZFELD, BC., HOGER, SJ. and Dietrich, DR., 2000. Cyanobacterial Toxins: Removal during Drinking Water Treatment, and Human Risk Assessment. *Environmental Health Perspectives*, vol. 108, no. 1, p. 113-122.

HOODA, PS., EDWARDS, AC., ANDERSON, HA. and MILLER, A., 2000. A review of water quality concerns in livestock farming areas. *The Science of the Total Environment*, vol. 250, no. 1/3, p. 43-167.

Instituto Brasileiro de Geografia e Estatística – IBGE, 2000. *Censo Demográfico*. Available from: <http://www.ibge.gov.br/>. Access in: 10 out. 2009.

Instituto Brasileiro de Geografia e Estatística – IBGE, 2002. *Pesquisa nacional de saneamento básico*. Available from: <http://www.ibge.gov.br/home/estatistica/populacao/condicaodevida/pnsb/default.shtm>. Access in: 10 out. 2009.

Instituto Brasileiro de Geografia e Estatística – IBGE, 2006. *Censo Agropecuário*. Available from: <http://www.ibge.gov.br/>. Access in: 10 out. 2009.

ISAAC, VJ., OLIVEIRA, C., AZEVEDO, CR. and MELLO, RQ., 2003. *Estudo das atividades pesqueiras no Lago Grande de Curuai. Região Médio Amazonas*. Brasília: ProVárzea/IBAMA. 45 p.

JOHNSON, PTJ., TOWNSEND, AR., CLEVELAND, CC., GLIBERT, PM., HOWARTH, RW., MCKENZIE, VJ., REJMANKOVA, E. and WARD, MH., 2010. Linking environmental nutrient enrichment and disease emergence in humans and wildlife.

Ecological Applications, vol. 20, no. 1, p. 16-29. PMid:20349828. PMCid:2848386. http://dx.doi.org/10.1890/08-0633.1

JUNK, WJ., 1997. General aspects of floodplain ecology with special reference to Amazonian floodplains, p. 3-17. In JUNK, WJ. *The Central Amazon Floodplain, Ecology of a Pulsing System.* Berlin: Springer-Verlag. 525 p.

JUNK, WJ., OHLY, JJ., PIEDADE, MTF. and SOARES, MGM., 2000. *The Central Amazon FloodplaIn Actual Use and Options for a Sustainable Management.* Leiden: Backhuys Publishers. 584 p.

LANDSBERG, JH., 2002. The Effects of Harmful Algal Blooms on Aquatic Organisms. *Reviews in Fisheries Science*, vol. 10, no. 2, p. 113-390. http://dx.doi.org/10.1080/20026491051695

McGRATH, DG., ALMEIDA, OT. and MERRY, FD. 2007. The Influence of Community Management Agreements on Household Economic Strategies: Cattle Grazing and Fishing Agreements on the Lower Amazon Floodplain. *International Journal of the Commons*, vol. 1, no. 1, p. 67-87.

MANKIEWICZ, J., Ska, MT., Walter, Z. and ZALEWSKI, M., 2003. Natural toxins from cyanobacteria. *Acta Biologica Cracoviensia,* Series Botânica, vol. 45, no. 2, p. 9-20.

MELACK, JM. and FORSBERG, B., 2001. Biogeochemistry of Amazon floodplain lakes and associated wetlands, p. 235-276. In MCCLAIN, ME., VICTORIA, RL., and RICHEY, JE. (Eds.), *The biogeochemistry of the Amazon basin and its role in a changing world.* New York: Oxford University Press. 384 p.

Ministério do Meio Ambiente – MMA, 2005. Resolução CONAMA n° 357 de 17 de março de 2005. *Dispõe sobre classificação dos corpos de água e diretrizes ambientais para o seu enquadramento, bem como estabelece as condições e padrões de lançamento de efluentes, e dá outras providências.* Brasília, 2005. 23 p.

MOURA, EAF., 2007. Água de beber, água de cozinhar, água de tomar banho: diversidade sócio ambiental no consumo da água pelos moradores da várzea de Mamirauá, Estado do Amazonas. *Cadernos de Saúde Coletiva*, vol. 15, no. 4, p. 501-516.

MOREIRA-TURCQ, PF., JOUANNEAU, B., TURCQ, B., SEYLER, P., WEBER, O. and GUYOT, JL., 2004. Carbon sedimentation at Lago Grande de Curuaí, a floodplain lake in the low Amazon region: insight into sedimentation rates. *Palaeogeography, Palaeoclimatology, Palaeoecology,* vol. 214, no. 1/2, p. 27-70.

MOSS, B., 1988. *Ecology of Freshwaters*. Oxford: Wiley Blackwell. 432 p.

NOVO, EMLM., BARBOSA, CCF., FREITAS, RM., SHIMABUKURO, YE., MELACK, JM. and Pereira-Filho, W., 2006. Seasonal changes in phytoplankton distribution in floodplain lakes in response to Amazon flood pulse derived from MODIS images. *Limnology*, vol. 7, no. 3, p. 153-161.

PINTO, WHA., TEIXEIRA, CV., SOARES, EC., BOCARDE, F., PARISE, M., FONSECA, SN. and FERREIRA, NC., 2007. Critérios para setorização e espacialização de dados pesqueiros na região de Parintins/AM e Santarém/PA. In *Anais do XIII Simpósio Brasileiro de Sensoriamento Remoto*, 2007. Florianópolis: INPE. p. 3019-3026.

PITOIS, S., JACKSON, MH. and WOOD, BJB., 2000. Problems associated with the presence of cyanobacteria in recreational and drinking waters. *International Journal of Environmental Health Research*, vol. 10, no. 3, p. 203 – 218. http://dx.doi.org/10.1080/09603120050127158

-, 2001. Sources of eutrophication problems associated with toxic algae: an overview. *Journal of Environmental Health*, vol. 64, no. 5, p. 25-32.

RICHLEN, ML., MORTON, S., JAMALI, EA., RAJAN, A. and ANDERSON, DM., 2010. The catastrophic 2008-2009 red tide in the Arabian gulf region, with observations on the identification and phylogeny of the fish-killing dinoflagellate Cochlodinium polykrikoides. *Harmful Algae*, vol. 9, no. 2, p.163-172. http://dx.doi.org/10.1016/j.hal.2009.08.013

RENÓ, VF., 2010. *Avaliação do desflorestamento da várzea do Baixo Amazonas nas décadas de 1970 e 2000 a partir de imagens Landsat*. São José dos Campos, São Paulo: Instituto Nacional de Pesquisas Espaciais. 105 p. Dissertação de Mestrado.

SÁ, LLC., VIEIRA, JMS., MENDES, RA., PINHEIRO, SCC., VALE, ER., ALVES, FAS., JESUS, IM., SANTOS, ECO. and COSTA, VB., 2010. Occurrence of toxic cyanobacterial bloom in the left margin of the Tapajós river, in the Municipality of Santarém (Pará State, Brazil). *Revista Pan-Amazônica de Saúde*, vol. 1, no. 1, p. 159-166.

SAMPAIO, EV., ROCHA, O., MATSUMURA-TUNDISI, T. and TUNDISI, JG, 2002. Composition and abundance of zooplankton in the limnetic zone of seven reservoirs of the Paranapanema river. *Brazilian Journal of Biology*, vol. 62, no. 3, p. 525-545.

SCHEFFER, M., CARPENTER, S., FOLEY, JA., FOLKE, C. and WALKER, B., 2001, Catastrophic shifts in ecosystems. *Nature,* vol. 413, p. 591-596. PMid:11595939. http://dx.doi.org/10.1038/35098000

SCHINDLER, DW., 2006. Recent advances in the understanding and management of eutrophication. *Limnology and Oceanography,* vol. 51, no. 1, p. 356-363. http://dx.doi.org/10.4319/lo.2006.51.1_part_2.0356

SCHMIDT, W., BORNMANN, K., IMHOF, L., MANKIEWICZ, J. and IZYDORCZYK, K., 2008. Assessing drinking water treatment systems for safety against cyanotoxin breakthrough using maximum tolerable values. *Environmental Toxicology and Water Quality*, vol. 23, no. 3, p. 337-345.

SILVA, HP., 2006. Sócio-ecologia da Saúde e Doença: os efeitos da invisibilidade nas ppulações caboclas da Amazônia. In Adams, C., Murrieta, RSS. and Neves, WA. (Orgs.). *Sociedades Caboclas Amazônicas*: Modernidade e Invisibilidade. São Paulo: Annablume/FAPESP. p. 319-345.

Silva, LHS., Hayakawa, RCS., Iespa, AAC., Iespa, CMD., Delfino, DO. and Lopes, FAS., 2007. Cianobactérias planctônicas da Lagoa Pitanguinha, RJ, Brasil. *Revista de Biociências*, vol. 13, no. 1/2, p. 63-70.

SOTERO-SANTOS, RB., CARVALHO, EG., Dellamano-Oliveira, MJ. and ROCHA, O., 2008. Occurrence and toxicity of an Anabaena Bloom in a tropical reservoir (Southeast Brazil). *Harmful Algae*, vol. 7, no. 5, p. 590-598. http://dx.doi.org/10.1016/j.hal.2007.12.017

TOLEDO-JR., AP., TALARICO, M., CHINEZ, SJ. and AGUDO, EG., 1983. A aplicação de modelos simplificados para a avaliação e processo de eutrofização em lagos e reservatórios tropicais. In *Anais do 12º Congresso Brasileiro de Engenharia Sanitária*, 1983. Camburiú. p.1-34.

TUNDISI, JG., TUNDISI, TM. and ROCHA, O., 2002. Ecossistema de águas interiores. In Rebouças, A., Braga, B. and Tundisi, JG. (Eds.). *Águas doces do Brasil*: Capital ecológico, uso e conservação. São Paulo: Escrituras Editora. p. 161-202.

TUNDISI, JG., MATSUMURA-TUNDISI, T., ARANTES JUNIOR, JD.,TUNDISI, JEM., MANZINI, NF. and DUCROT, R., 2004. The response of Carlos Botelho (Lobo, Broa) reservoir to the passage of cold fronts as reflected by physical, chemical and biological variables. *Brazilian Journal of Biology*, vol. 64, no. 1, p. 177-186.

VIEIRA, JMS., AZEVEDO, MTP., AZEVEDO, SMFO., HONDA, RY. and CORRÊA, B., 2005. Toxic cyanobacteria and microcystin concentrations in a public water supply reservoir in the Brazilian Amazonia region. *Toxicon*, vol. 45, p. 901-909. PMid:15904685. http://dx.doi.org/10.1016/j.toxicon.2005.02.008

WETZEL, RG., 2001. *Limnology*: lake and river ecosystems. San Diego: Elsevier Academic Press. 1006 p.

WETZEL, RG. and LIKENS, GE., 1991. *Limnological analysis*. New York: Springer-Verlag. 391 p.

WHITEHEAD, PG., WILBY, RL., BATTARBEE, RW., KERNAN, M. and WADE, AJ., 2009. A review of the potential impacts of climate change on surface water quality Hydrological Sciences. *Journal des Sciences Hydrologiques*, vol. 54, no. 1, p. 101-123. http://dx.doi.org/10.1623/hysj.54.1.101

World Health Organization – WHO, 1996. *Water Quality Assessments* – A Guide to Use of Biota, Sediments and Water in Environmental Monitoring. Cambridge: World Health Organization, University Press. 651 p.

YUNES, JS, CUNHA, NT., BARROS, LP., PROENÇA, LAO. and MONSERRAT, JM., 2003. Cyanobacterial Neurotoxins from Southern Brazilian freshwaters. *Comments on Toxicology*, vol. 9, no. 2, p. 103-115. http://dx.doi.org/10.1080/08865140302426

YUNES, JS., 2009. Florações de microcystis na Lagoa dos Patos e o seu estuário: 20 anos de estudos. *Oecologia Brasiliensis*, vol. 13, no. 2, p. 313-318. http://dx.doi.org/10.4257/oeco.2009.1302.06