Scientific Research and Essays Vol. 6(10), pp. 2069-2077, 18 May, 2011
Available online at http://www.academicjournals.org/SRE
DOI: 10.5897/SRE10.735
ISSN 1992-2248 ©2011 Academic Journals

Full Length Research Paper

Dynamics of plankton and fish in a subtropical temporary wetland: Rice fields

Lúcia Helena Ribeiro Rodrigues[1,2]*, Eliete Bertazzo Canterle[1,2], Vanessa Becker[1,3], Vanessa Gazulha[2], Ângela Hamester[2] and David da Motta Marques[1,2]

[1]Laboratório de Ecotecnologia e Limnologia, Instituto de Pesquisas Hidráulicas, Universidade Federal do Rio Grande do Sul, Av. Bento Gonçalves 9500, 91501-970, Porto Alegre, RS, Brazil.
[2]Programa de Pós Graduação em Recursos Hídricos e Saneamento Ambiental, Instituto de Pesquisas Hidráulicas, Universidade Federal do Rio Grande do Sul, Av. Bento Gonçalves 9500, 91501-970, Porto Alegre, RS, Brazil.
[3]Programa de Pós Graduação em Engenharia Sanitária, Centro de Tecnologia, Universidade Federal do Rio Grande do Norte, Av. Senador Salgado Filho 3000, 59078-970, Natal, RN, Brazil.

Accepted 12 January, 2011

Rice fields are temporary wetlands that harbor many of the same species that breed in natural temporary ponds. These systems have a complex limnology, characterized by rapid physical, chemical, and biological changes. The goal of this study was to evaluate the role of nutrients in the plankton and fish dynamics during a production cycle, based on the auto-ecology of the species related to their adaptations to environmental temporal changes in an irrigated rice field in Southern Brazil. The principal components analysis (PCA) indicated a temporal gradient driven by nutrient availability, grouping sampling periods according to the production cycle. ANOVA indicated temporal differences in the limnological variables during the development of the rice field production cycle. Linear regression showed a positive relationship between chlorophyll *a*, nutrients and biomass of small and medium filter-feeders. In contrast, planktivorous fish biomass was inversely related to chlorophyll *a*. This study showed both top down and bottom up processes simultaneously regulating the primary production in the rice field wetland along a temporal gradient the rice production cycle.

Key words: Chlorophyll *a*, filter-feeders, planktivorous fish, temporal gradient.

INTRODUCTION

Irrigated rice fields are an integral part of the landscapes of tropical and subtropical regions. They are temporary wetlands that harbor many individuals of the same species that breed in natural temporary ponds (Roger, 1996; Lawler, 2001). Therefore the rice agro-ecosystem has the potential to help sustain the regional biodiversity of many invertebrates and vertebrates. Worldwide, rice fields have been recognized as having considerable potential value for many species of aquatic invertebrates, plants, and vertebrates such as fish, amphibians, and birds (Fernando et al., 1979, 1993; Burhanuddin, 1993; Brouder and Hill, 1995; Elphick and Oring, 1998, 2003; Bambaradeniya and Amarasinghe, 2003).

Similar to natural areas of wetlands, rice cultivation provides a habitat mosaic of temporary and more permanent waters (Bambaradeniya, 2000; Lawler, 2001). These systems have a complex limnology, characterized by rapid physical, chemical, and biological changes (Bambaradeniya, 2000). The greater environmental heterogeneity in the rice field ecosystem, operating on a temporal scale, may be a major contributing factor to its rich and varied biodiversity (Bambaradeniya et al., 2004).

The organisms that live in these types of heterogenic habitats need therefore, to be very well adapted to these rapidly changing conditions, including the loss of water during the dry season (Bambaradeniya et al., 2004). The survival of these organisms depends largely on exceptional physiological tolerance or effective

*Corresponding author. E-mail: luciarrodrigues@gmail.com.

immigration and emigration abilities (Williams, 1987). Furthermore, compared to other temporary freshwaters, the organisms in rice fields must cope with various agronomic practices, which make the prevailing conditions more complicated (Bambaradeniya, 2000; Bambaradeniya et al., 2004).

Limnologically, the rice field is characterized by its temporary nature, and the high flux of organic matter, both allochthonous and autochthonous. The changes from wet to dry conditions cause rapid demineralization of organic matter, and both aerobic and anaerobic activity can be intense at times (Fernando, 2005). With flooding, the remineralization of organic matter and the first biological processes of the wet phase are initiated. Temperatures are high, and there is an abundance of nutrients. The impacts of nutrient dynamics are reflected in the community structure and interactions within the food web (Vakkilainen et al., 2004).

The availability of nutrients has an essential role in controlling the composition and biomass of phytoplankton communities (Reynolds, 1997). Nitrogen and phosphorus loading determine many features of aquatic systems (Reynolds, 2006). A consensus has emerged that nutrients remain very important in shallow systems, but the extent to which their potential influence may be realized is very much a function of food-web structure and how it can be modified by nutrient loading. The rice field releases inocula of planktonic bacteria and phytoplankton into the water column, where they most likely use available nutrients and dissolved organic carbon (Kobayashi et al., 2009).

On the other hand, the effects of filter-feeding planktivorous fish on the plankton communities of aquatic ecosystem have been studied by Lazzaro (1987), Starling and Rocha (1990), Starling (1993), Fukushima et al. (1999) and others. However, the effects of planktivorous fish on plankton communities should depend on the fish biomass (Lazzaro et al., 1992; Drenner et al., 1996; Starling et al., 1998) and the composition of fish community also affected the species composition and size structure of the phytoplankton community (Figueredo and Giani, 2005).

The present study was carried out in an irrigated rice field in Southern Brazil. This is among the regions in the country that are most influenced by rice fields, with extensive rice-growing areas. The Taim Hydrological System, which is bordered by areas of rice fields, has two sometimes conflicting functions: (1) Conservation, through the Taim Ecological Station; and (2) The supply of water for rice production. In recent decades, the Taim system has undergone unregulated manipulation, irrigation, and outflow control for conservation, so that its hydrological signature and its present situation no longer represent natural conditions (Crossetti et al., 2007).

The goal of this study was to evaluate the role of variations in nutrients and its effect on the dynamics of plankton and fish communities during a production cycle, based on the auto ecology of the species related to their adaptations to temporal environmental changes.

MATERIALS AND METHODS

Study site

The study was carried out in two irrigated rice fields of Santa Vitória do Palmar municipality, in the state of Rio Grande do Sul (Figure 1), located in Southern Brazil. Its region contains the largest area of irrigated rice fields in the country, with comparable production to countries such as Australia, Japan, and the USA (~7 tons ha^{-1} $year^{-1}$) (Azambuja et al., 2004). The regional climate is subtropical, with a mean annual temperature of 16ºC and precipitation between 1800 and 2200 mm (Cfa type; Kottek et al., 2006). The study areas have mainly sandy or clay soils: Area 1 (A1) - Sandy, with 4 ha (S 33.2885º; W 53.0925º), and Area 2 (A2) - Clay, with 1 ha (S 33.2872º; W 53.0886º). In the rice fields, glyphosate is ordinarily applied in two phases: During tillage (4 L ha^{-1}), and the beginning of rice emergence (2 L ha^{-1}). The rice fields are fertilized with urea (200 kg ha^{-1}), before irrigation and after the rice emerges.

Sampling and field measurements

With regard to the water flow through the rice field, in each sampling area (A1) and (A2), sampling was carried out in the inlet (I), in the central area (C), and in the outlet (O). Sampling was performed from January 2006 up to March 2006, with four collections, 20 days apart, covering the entire water cycle of rice production. The first sampling (period 1) was performed just after the rice field was flooded; samplings two and three (periods 2 and 3) in the mid-cycle; and the last sampling just one day before the field was drained (period 4).

Water temperature, dissolved oxygen, and pH were measured with a multi-parameter probe (Yellow Springs Instruments model YSI 6920). Water samples for chemical analysis and chlorophyll *a* were collected at the surface, with a bottle (1 l). Zooplankton samples were taken by filtering 10 L of water through plankton net (65 µm mesh size) and fixed with 4% formaldehyde. Fish captures were made overnight (15 h) by using three minnow traps for each sampling point. Fish were preserved with 4% formaldehyde.

Sample analysis

The nutrients total phosphorus (TP), soluble reactive phosphorus (SRP), total nitrogen (TN), and nitrate (NO_3) were analyzed according to Mackereth et al. (1989). Dissolved organic matter (DOM) was analyzed by the spectrophotometric method (Strome and Miller, 1978). Total solids (TS) were estimated according to APHA (1999), and soluble reactive silicon (SRSi) was measured by the photometric method, using a commercial kit (Si Merck Spectroquant® kit for silicate - sulfuric acid). Carbon (dissolved organic, DOC; and dissolved inorganic, DIC) was analyzed using a total organic carbon (TOC) analyzer (Shimadzu VCPH). Chlorophyll a was extracted from GF/F filters in 90% ethanol (Jespersen and Christoffersen, 1987) and measured by the spectrophotometric method (APHA, 1999). Quantitative analysis for zooplankton was performed using a Sedgwick-Rafter chamber (APHA, 1999). The functional groups of zooplankton were defined based on the auto-ecology of the species, food size, and feeding habits: Small filter-feeders up to 200 µm GALD (rotifers), medium filter-feeders up to 1 mm GALD (cladocerans and copepod nauplii), efficient filter-feeders more than 1 mm GALD (cladocerans and calanoid copepodites and adults), carnivores (cyclopoid copepods) and detritivores (protists > 65 µm). Zooplankton biomass (fresh weight) was estimated from biovolume by applying the closest geometric formulae (Bottrell et al., 1976; Dumont et al., 1975; Ruttner-Kolisko, 1977; Malley et al., 1989). Fish were identified, and the standard length (centimeters)

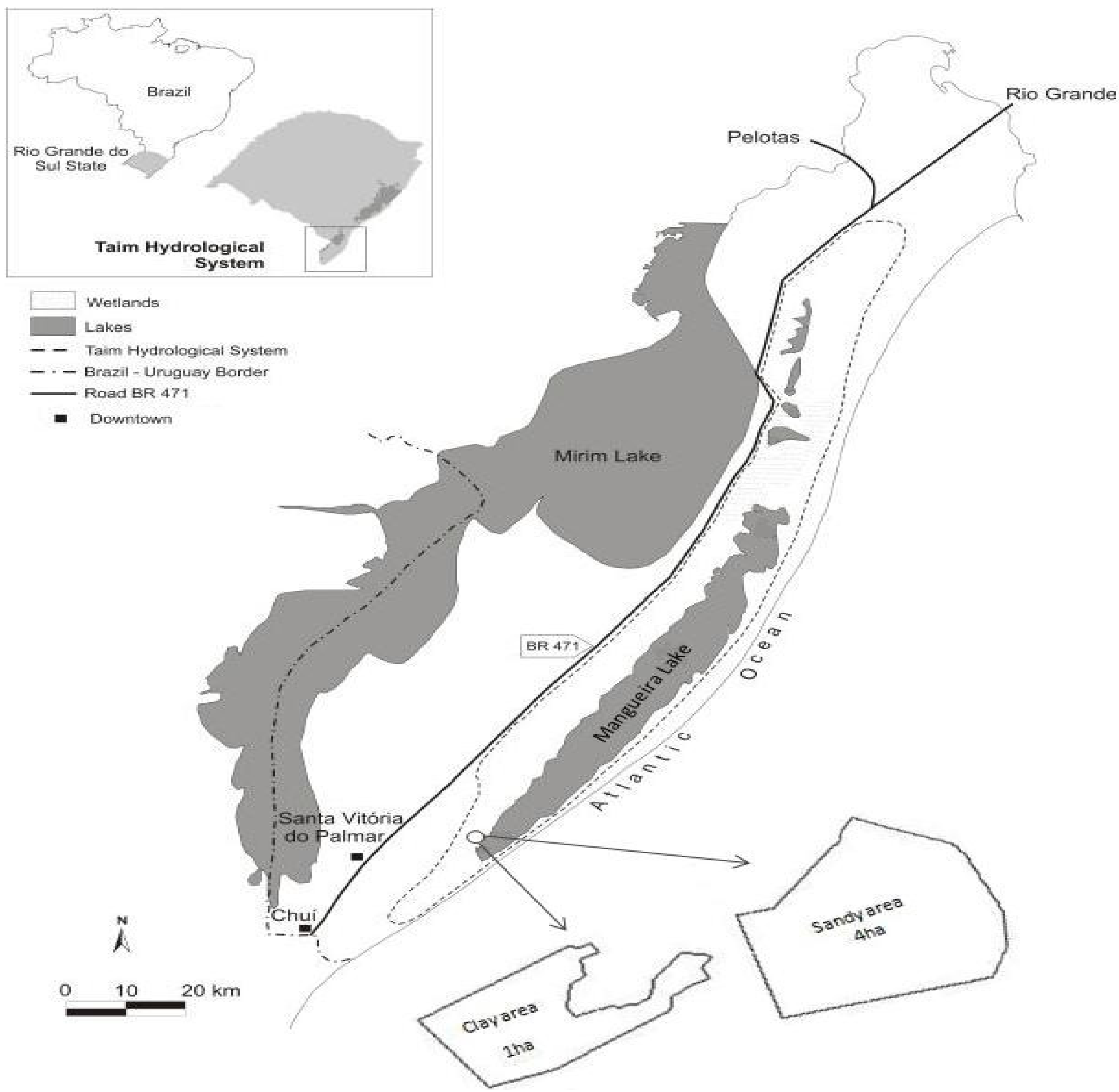

Figure 1. Taim hydrological system and Mangueira Lake situated in Santa Vitória do Palmar City in Southern Brazil, showing the rice fields location.

and total weight (grams) of each individual were measured. The functional groups of fish were defined based on the feeding habits of species: Planktivorous, piscivorous and omnivorous, following Lazzaro et al. (2003).

Statistical analysis

The principal components analysis (PCA) was performed using PC-ORD program version 4.0 (McCune and Mefford, 1999). This analysis was undertaken to determine the spatial and temporal changes in the physical and chemical conditions. The temporal differences were tested using analysis of variance with repeated measures (ANOVA*mr*) and linear regression (Statview ver. 5.0). A simple regression was used to identify possible relationships among nutrients (P, N, C), plankton biomass (chlorophyll *a*, zooplankton), and fish biomass, after $\log_{10}$ transformation.

RESULTS

Limnological scenario

During the study period, both rice fields, A1 (sandy) and A2 (clay), had similar temperature and pH. Mean concentrations of dissolved oxygen were higher in rice field A1 (8.2 mg.L^{-1}) than in A2 (6.6 mg.L^{-1}) (Table 1). The concentrations of nutrients analyzed and chlorophyll a were highest at the beginning of culture, just after the rice field was flooded, and declined throughout the production

Table 1. Mean values and standard deviations of the limnological variables measured during the study.

Parameter	Sampling 1		Sampling 2		Sampling 3		Sampling 4	
	Sandy	Clay	Sandy	Clay	Sandy	Clay	Sandy	Clay
Water temperature (ºC)	22.1	21.2	27.2	26.3	23.8	22.8	26.3	27.4
pH	7.8±0.2	7.4±0.4	7.3±0.3	7.2±0.1	6.7±0.4	6.9±0.2	7.6±0.4	7.3±0.4
Dissolved oxygen ($mg.L^{-1}$)	7.6	5.9	10.6	6.8	9.9	7.7	5.9	5.5
Total Solids ($mg.L^{-1}$)	310±102	274±96	238±20	247±12	221±10	211±11	201±61	201±17
DOM (UV_{DOC} – 254 nm)	0.44±0.26	0.30±0.13	0.14±0.03	0.18±0.03	0.03±0.03	0.05±0.03	0.02±0.01	0.01±0.01
DIC ($mg.L^{-1}$)	19.66±4.4	24.79±4.5	21.82±2.3	28.32±3.5	25.47±2.5	26.38±1.1	27.74±2.8	29.19±3.2
DOC ($mg.L^{-1}$)	15.11±8.6	18.33±10.6	12.52±5.9	10.16±2.7	7.12±1.7	6.33±0.8	8.30±1.7	7.42±1.9
SRSi ($mg.L^{-1}$)	3.22±0.77	3.47±0.68	1.03±0.90	1.56±1.04	1.76±0.84	2.14±0.48	0.36±0.33	0.27±0.09
TP ($\mu g.L^{-1}$)	5.90±4.51	3.23±1.92	2.34±1.51	2.83±1.74	1.03±0.31	1.52±0.21	0.16±0.03	0.18±0.02
SRP ($\mu g.L^{-1}$)	2.82±1.31	1.21±0.88	1.30±0.88	1.25±0.90	0.14±0.03	0.18±0.03	0.03±0.02	0.02±0.01
TN ($\mu g.L^{-1}$)	100±20	170±70	40±20	40±10	30±20	20±10	20±10	10±5
NO_3 ($\mu g.L^{-1}$)	50±40	50±20	20±10	30±20	10±5	10±5	NQ	NQ
Chlorophyll *a* ($\mu g.L^{-1}$)	39.5±17.3	42.7±21.3	29.3±21.8	33.2±22.8	2.5±1.4	2.5±0.6	2.2±1.2	1.6±0.6

DOM, dissolved organic matter; DIC, dissolved inorganic carbon; DOC, dissolved organic carbon; SRSi, soluble reactive silicate; TP, total phosphorus; SRP, soluble reactive phosphorus; TN, total nitrogen; NO_3, nitrate.

cycle.

The principal components analysis (PCA) evaluated the main trends among limnological variables in the rice fields (Figure 2). The PCA using 13 abiotic variables explained 75.9% of the data variability on the first three axes (axis 1= 51.6%; axis 2= 13.0%). The most important variables for axis 1 ordination were TP (-0.92), NO_3 (-0.89), DOM (-0.85), TS (-0.83), SRP (-0.82), DIC (0.74), SRSi (-0.73), chlorophyll a (-0.71), water temperature (0.67), and DOC (-0.67). In regard to axis 2, the most important variables were TN (-0.73) and dissolved oxygen (0.52). The PCA results indicated a temporal gradient driven by nutrient availability (Figure 2). On the negative side of axis 1, sampling units for period 1 were correlated with the highest values of dissolved nutrients (SRP, NO_3, SRSi), TP, TS, DOM, and chlorophyll a; whereas on its positive side the sampling units for period 4 were ordered with higher values of temperature and DIC. On the negative side of axis 2, all the sample units for period 3 were ordered with higher concentrations of total nitrogen and, on the positive side, the sample units for period 2 were correlated with higher values of dissolved oxygen. Moreover, PCA revealed a homogeneous behavior between the sampling stations and the environmental variables in this system. Sampling stations were grouped by sampling periods, with no evident of spatial gradient (Figure 2).

ANOVA showed temporal differences ($P<0.05$) among the limnological variables during the course of the rice field production cycle. Linear regressions indicated that SRSi, ST, DOM, DOC, TP, SRP, Chla, TN, and NO_3 showed decreasing trends ($P<0.05$), while DIC showed an increasing trend ($P=0.05$) throughout the production cycle. A spatial gradient was not identified by ANOVA or regression analysis.

Community structure

A total of 74 zooplankton species was identified.

Copepods predominated in biomass during all study period. High percentage of this organisms was founded in both rice fields, 80% in sandy area and 66% in clay area. Cladocerans were the most representative in clay area (28%), whereas rotifers (4%) and protists (2%) were less important representatives. In sandy area, cladocerans (6%), rotifers (8%) and protists (5%) presented low percentage (Figure 3).

Among the rotifers, the genus *Lecane* was the most important, especially *Lecane bulla* (Gosse, 1851); *L.* cf. *papuana* (Murray, 1913), and *L.* cf. *inermis* (Bryce, 1892). For the cladocerans, *Moina minuta* (Hansen, 1899), *Macrothrix triserialis* (Brady, 1886) and *Ceriodaphnia cornuta* (Sars, 1885) were the most numerous species. *Eucyclops serrulatus* (Fischer, 1851) was the most abundant species of copepod. Considering the biomass functional groups, medium filter-feeders were the most numerous (69.20%), whereas efficient filter-feeders (21.73%), small filter-feeders (5.12%); detritivores (2.15%), and carnivores (1.79%) were the least numerous components of the community. The fish fauna comprised 11 species, in 7 families (Table 2). The planktivorous fishes *Astyanax jacuhiensis* (Cope, 1894) (42.45%) and *A. eigenmanniorum* (Cope, 1894) (12.36%), and the piscivorous fishes *Hoplias malabaricus* (Bloch, 1794) (28.24%) and *Crenicichla lepidota* (Heckel, 1840) (11.15%) were the most important species in terms of biomass. The omnivorous fishes *Gymnogeophagus*

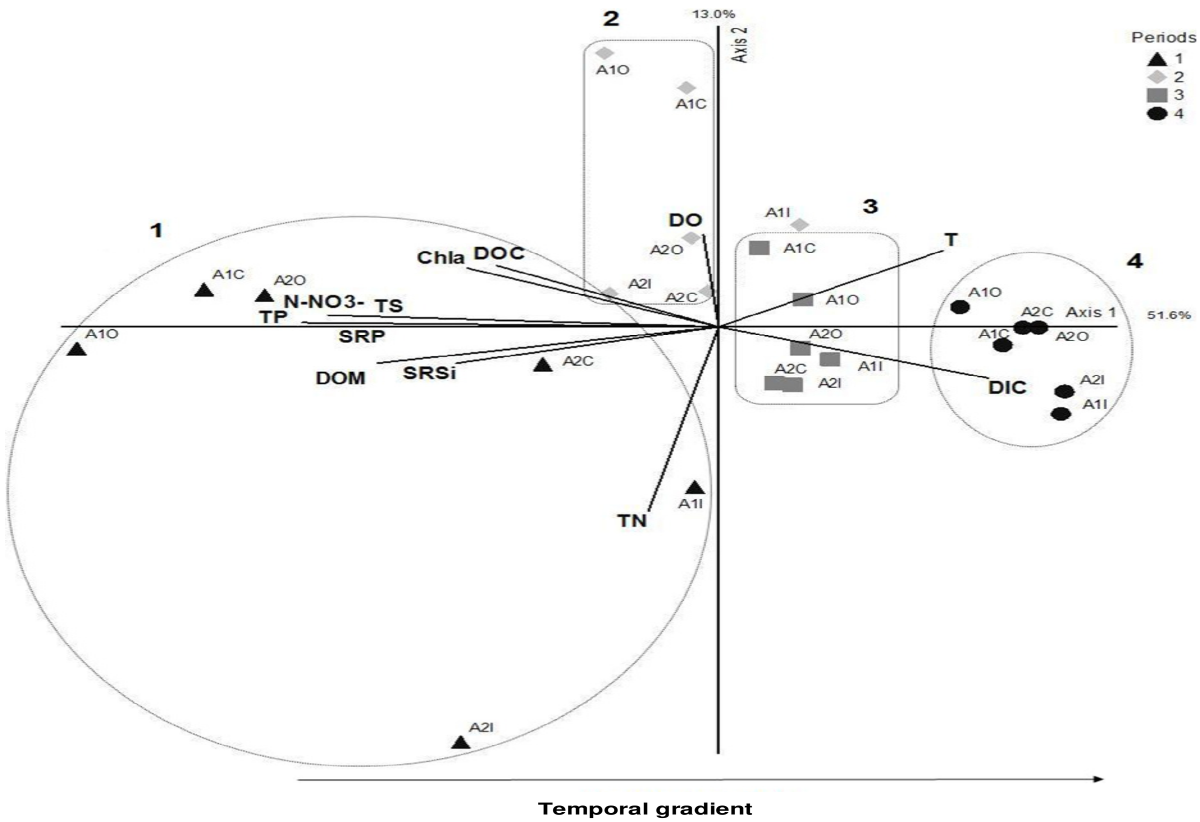

Figure 2. Results of the principal components analysis (PCA) applied to environmental variables in two rice fields in Santa Vitória do Palmar, Southern Brazil. Sample units= sampling periods 1, 2, 3, 4; A1= sandy area; A2= clay area; I= inlet; C= central point; O= outlet. T= water temperature; TP= total phosphorus; SRP= soluble reactive phosphorus; TN= total nitrogen; NO_3= nitrate; SRSi= soluble reactive silicate; DIC= dissolved inorganic carbon; DOC= dissolved organic carbon; Chl a= chlorophyll a; TS= total solids; DOM= dissolved organic matter.

rhabdotus (Hensel, 1870) and *Hyphessobrycon luetkenii* (Boulenger, 1887) represented 5.8%. Linear regressions of log-transformed data demonstrated a positive relationship between chlorophyll a and TP, SRP, NO_3, DOC, small and medium filter-feeders (Table 3). In contrast, planktivorous fish biomass was inversely related to chlorophyll a (Table 3).

Statistically significant ($P<0.05$) relationships between DOC and phosphorous (TP and SRP), zooplankton biomass (small and medium filter-feeders) and planktivorous fish biomass were also identified (Table 3).

DISCUSSION

Our results indicated a temporal gradient in nutrient availability in these rice fields. However, the limnological variables did not display any horizontal pattern among sampling stations. In general, the aquatic phase of a rice field is temporary and seasonal (Fernando, 1993). These systems can be considered as a modified marsh ecosystem. However, farming practices change the natural physical, chemical, and biological conditions, turning them less favorable for some organisms, but, also temporarily, more favorable for others (Heckman, 1979).

Four distinct periods during the development of these ecosystems were identified, according to the results of the PCA. The first period was characterized by the highest concentrations of nutrients, in the initial growing phase following the flooding period. The second and third periods were transition periods, with gradual modifications in the physical structure of the systems, when the rice plants were growing and nutrient concentrations were decreasing. The fourth period was characterized by high concentrations of DIC, probably due to transformation of DOC, because of the highest temperatures and light intensity, considering that this period of the growing cycle coincided with the end of the summer.

The tendency for decreases in nutrients in the rice fields observed throughout the study may be associated with the incorporation of these nutrients by the plants and/or by the sediment during the production cycle, or by the phytoplankton metabolism, according to the results of the PCA and regression analyses. Organisms which survive in this environment have wide tolerance limits for these rapid changes, and can take advantage of the abundant food, low competition, and little predation (Fernando, 1993). The concentrations of dissolved

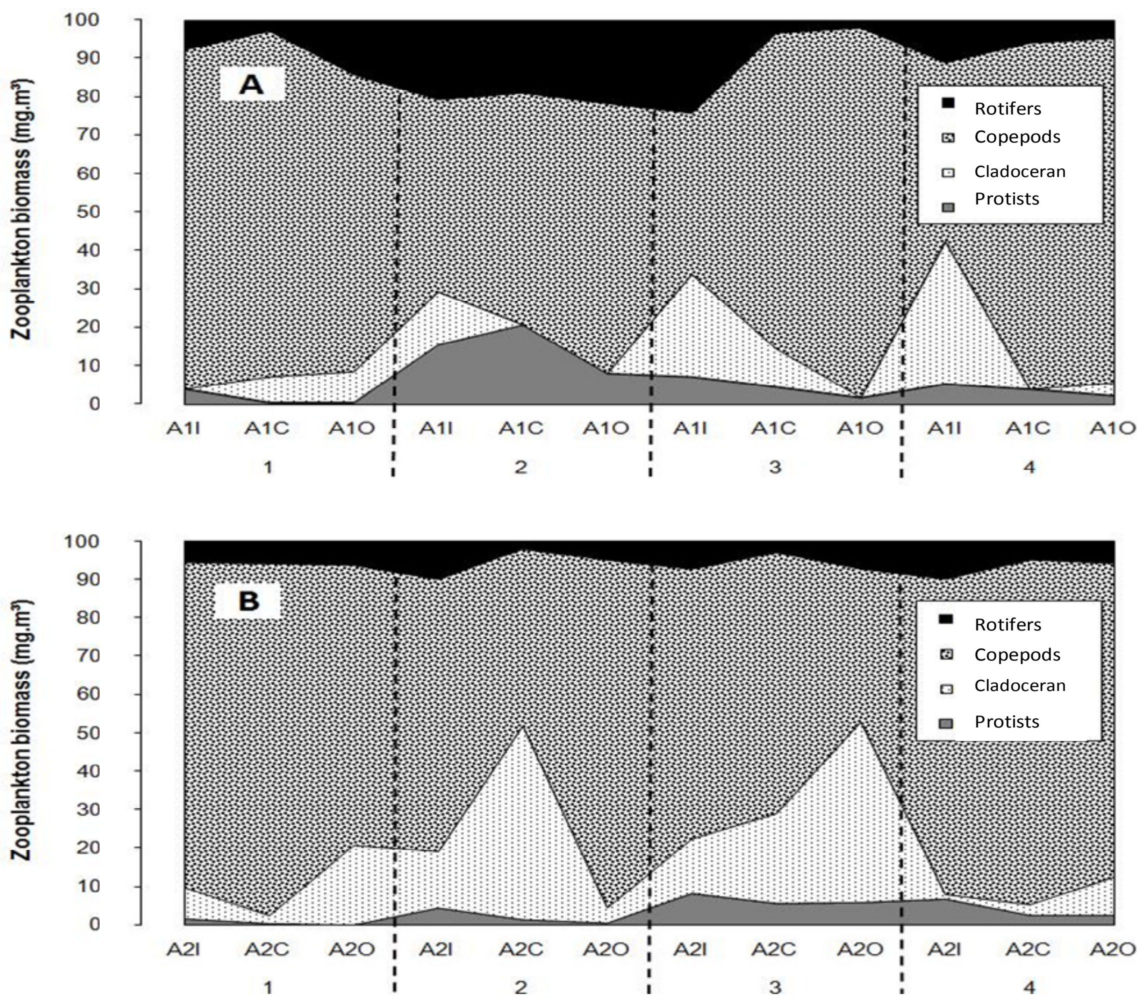

Figure 3. Community structure of zooplankton in two rice fields in Santa Vitória do Palmar, southern Brazil. Sample periods 1, 2, 3, 4; A= A1 (sandy area); B= A2 (clay area); I= inlet; C= central point; O= outlet.

Table 2. Fish species captured during the study.

Family	Species
Anablepidae	*Jenynsia multidentata* (Jenyns, 1842)
Curimatidae	*Cyphocharax voga* (Hensel, 1870)
Erythrinidae	*Hoplias malabaricus* (Bloch, 1794)
Characidae	*Astyanax eigenmanniorum* (Cope, 1894) *A. jacuhiensis* (Cope, 1894) *H yphessobrycon luetkenii* (Boulenger, 1887) *Oligosarcus robustus (*Menezes, 1969)
Callichthyidae	*Corydoras paleatus* (Jenyns, 1842)
Cichlidae	*Gymnogeophagus rhabdotus* (Hensel, 1870) *Crenicichla lepidota* (Heckel, 1840)
Poeciliidae	*Cnesterodon decemmaculatus* (Jenyns, 1842)

Table 3. Results of linear regressions describing the relationships between chlorophyll *a*, phosphorus (TP and SRP), zooplankton biomass (small and medium filter-feeders) and planktivorous fish biomass (dependent variable) and abiotic/biotic factors.

Dependent variable	Independent variable	R^2	F	P
	TP	0.51	23.13	<0.001
	SRP	0.35	11.93	0.002
	NO_3	0.48	20.16	<0.001
Chlorophyll *a*	DOC	0.53	24.98	<0.001
	Small filter-feeders	0.36	12.30	0.002
	Medium filter-feeders	0.21	5.96	0.023
	Planktivorous fish	0.28	8.67	0.008
TP		0.29	8.84	0.007
SRP		0.24	7.10	0.014
Small filter-feeders	DOC	0.39	13.88	0.001
Medium filter-feeders		0.32	10.53	0.004
Planktivorous fish		0.30	9.15	0.006

TP, total phosphorus; SRP, soluble reactive phosphorus; NO_3, nitrate; DOC, dissolved organic carbon.

inorganic nutrients and DOM in wetlands, like rice fields, are generally higher than those recorded in lakes and reservoirs (Wetzel, 2001).

Autochthonous sources of DOC are the phytoplankton, the aquatic macrophytes and the periphyton (Farjalla et al., 2004). On the other hand, DIC was an important variable indicated by the PCA in the final phase of the production process (period 4), and it is indirectly related to the fish biomass, since it was negatively related to DOC. In environments with wide fluctuations of the DOC content, such as rice fields, the photoxidation of DOC to inorganic carbon is mediated by UVA, UVB, and PAR, and results in the production of DIC (Granéli et al., 1998). This is one hypothesis to explain the fluctuation of DOC and DIC observed in the present study.

The effects on phytoplankton, through bottom-up, nutrient-mediated processes in lakes, are well understood. An increase in nutrients, through a myriad of bottom-up mechanisms, can increase the phytoplankton biomass until another factor becomes limiting (Williams and Moss, 2003). A deficiency of phosphorus is commonly observed in rice fields (Fernando, 2005). In this study, TP and SRP showed a tendency to decrease, possibly, being incorporated into the metabolism of the ecosystem, especially in the phytoplankton, since the highest concentrations of chlorophyll a in the initial phase of the cycle were associated with the highest concentrations of TP and SRP. There was a positive relationship between chlorophyll a and TP, and SRP and NO_3^-. Considering the N:P ratio, environments limited by N have a TN:TP < 9, while P is considered limiting when TN:TP > 22 (Sondergaard et al., 1999). In this study, the mean value of TN:TP was 42, indicating that the system could be P-limited for phytoplankton growth. Considering the dissolved nutrient concentrations and the algal requirements based on half-saturation constants for growth, algae in the rice fields can be considered as limited by P (Ks=3.1 µg.L^{-1}, Reynolds, 2006) during the entire period of the study (mean SRP=0.87 µg.L^{-1}).

Aquatic organisms in rice fields cover the entire spectrum of fresh water fauna. Aquatic invertebrate animals inhabiting the rice field water have been broadly divided into 'neuston' that include surface dwelling insects, 'zooplankton' which includes minute organisms such as protozoans, micro-crustaceans and rotifers, 'nekton' which includes aquatic insects and their larvae and 'benthos', which includes bottom dwelling annelid worms, nematodes and molluscs (Heckman, 1979; Fernando, 1993; Halwart,1994; Bambaradeniya, 2000).

Of the aquatic organisms in rice fields, zooplankton consisting largely of micro-crustaceans and rotifers are probably the most widely studied group. A survey of the aquatic invertebrate fauna of tropical rice fields by Fernando (1977) showed that diverse zooplankton communities occur in rice-fields of West Malaysia, Burma and Sri Lanka. This high diversity has been attributed to the abundance of natural marshes and relatively high precipitation in these countries.

In this study, 74 zooplankton species were found in rice fields, representing more than 85% of the richness observed in the study region (Gazulha, 2004). However, the composition of the species observed in Taim Hydrological System was different from that in rice fields, mainly due to the dominance of cladocerans (46%) and rotifers (36%), while copepods were lower representatives (17%).

The shift from a dry to a wet environment in rice cultures is probably a key factor in the composition of the zooplankton community. This shift probably favors organisms that have appropriate survival and reproduction strategies, such as dormancy, and production of resistant eggs that are deposited on the sediment and will quickly hatch when conditions are favorable. Non-encysted dormancy has been observed for copepod species, especially late copepodite stages, while rotifers and cladocerans are known for the production of resistant eggs. *Eucyclops serrulatus*, the copepod species that contributed most to the zooplankton biomass, was recognized by Nandini and Sarma (2007) as very tolerant to extreme environmental conditions, such as in rice cultures.

Our results revealed the importance of planktivorous fish in controlling algal biomass. The negative relationship between planktivorous fish biomass and DOC, indirectly suggests a positive relationship between fish biomass and DIC, although this was not statistically significant. The highest concentrations of DIC are associated with the final phase of the rice production cycle. In this phase, the system is more “mature” and has a more complex spatial structure caused by the growth of the rice plants. When the fish enter the paddies, they find more structured habitats and will remain longer, resulting in the high capture rate and biomass observed in the middle and at the end of the culture cycle.

Fishes are an integral part of the rice field fauna especially in the tropics (Fernando, 1993, 1995, 1996). Fresh water fish species in the rice fields of Sri Lanka, Thailand and Philippines have been recorded by Fernando (1956), Heckman (1979) and Halwart (1993) respectively. Fernando (1956) listed 35 species of fish inhabiting a rice field ecosystem in Sri Lanka. A study by Lai and Chua (1980) listed 16 fish species mainly from the reservoir areas of the Muda rice irrigation system in Malaysia.

Fish checklist in this work resulted in 11 species, representing only 18% of the richness observed in the study region (Garcia et al., 2006). However, the composition of the species observed in Taim Hydrological System, differently of zooplankton, was similar from that in rice fields, mainly due to the dominance of Characidae showing the highest species richness.

In the study rice fields, the control of aquatic plants with herbicide (glyphosate) was carried out during the tillage phase and at the beginning of the growing season. Glyphosate, one of the main herbicides used in rice fields, is a non-selective systemic herbicide used to kill weeds, especially sedges and grasses (Shibayama, 2001). Despite this, no sign was found of detrimental effects of herbicides in the rice fields. However, if rice fields are to be used as conservation tools, the use of herbicides and other chemicals must be carefully evaluated.

Conclusions

Our study confirmed the important role of the availability of nutrients in the dynamics of plankton biomass and fish in rice fields, and the importance of planktivorous fish in controlling algal biomass in these systems. Population and community structure is strongly influenced by environmental gradients and habitat structure. The results showed both top-down and bottom-up processes operate simultaneously regulating the primary production in the rice-field wetland along a temporal gradient the rice production cycle.

ACKNOWLEDGMENTS

We are thankful to the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq-Long Term Ecological Research Program) of Brazil for financial support. We are grateful to Dr. Luciane Crossetti for her kind revision and valuable comments on the manuscript and finally, to Dr. Janet W. Reid (JWR Associates) for revising the English text.

REFERENCES

American Public Health Association (APHA) (1999). Standard methods for the examination of water and wastewater. 20th edn. American Public Health Association Inc., Washington D.C.

Azambuja IHV, Vernetti Jr. FJ, Magalhães Jr. AM (2004). Socioeconomic aspects of Rice production. In Gomes AS, Magalhães Jr. AM (eds), Irrigated Rice in Southern Brazil. Embrapa, Pelotas, RS: pp. 23-44.

Bambaradeniya CNB (2000). Ecology and biodiversity in an irrigated rice field ecosystem in Sri Lanka. PhD thesis. University of Peradeniya, Sri Lanka, p. 525.

Bambaradeniya CNB, Amerasinghe FP (2003). Biodiversity associated with the rice field agroecosystem in Asian countries: a brief review. Int. Water Manag. Instit., 63: 1-29.

Bambaradeniya CNB, Edirisinghe JP, de Silva DN, Gunatilleke CVS, Ranawana KB, Wijekoon S (2004). Biodiversity associated with an irrigated rice agro-ecosystem in Sri Lanka. Biodiversity and Conserv., 13: 1715-1753.

Bottrell HH, Duncan A, Gliwicz ZMV, Grygierek E, Herzig A, Hillbricht-Ilkowska A, Kurasawa H, Larsson P, Weglenska T (1976). A review of some problems in zooplankton production studies. Nor. J. Zool., 24: 419-456.

Brouder SM, Hill JE (1995). Winter flooding of ricelands provides waterfowl habitat. Cali. Agric., 49: 1-58.

Burhanuddin MN (1993). Use and management of riverine wetlands and rice fields in Peninsula Malaysia. In Towards Wise Use of Asian Wetlands, Isozaki H, Ando M, Natori Y (eds). Proceedings of the Asian Wetland Symposium, International Lake Environment Committee Foundation, Kusitsu City, Japan; pp.15-20.

Crossetti LO, Cardoso LS, Callegaro VLM, Alves da Silva SM, Werner V, Rosa ZM, Motta Marques DML (2007). Influence of the hydrological changes on the phytoplankton structure and dynamics in a subtropical wetland-lake system. Acta Limnol. Bras., 19: 315-329.

Dumont HJ, Van de Velde I, Dumont S (1975). The dry weight estimate of biomass in a selection of Cladocera, Copepoda and Rotifera from the plankton, periphyton and benthos of continental waters. Oecol., 19: 75-97.

Drenner RW, Smith JD, Threlkeld ST (1996). Lake trophic state and the limnological effects of omnivorous fish. Hydrobiol., 319:213-223.

Elphick CS, Oring LW (1998). Winter management of Californian rice fields waterbird comment. J. Appl. Ecol., 35: 95-108.

Elphick CS, Oring LW (2003). Conservation implications of flooding rice fields on winter waterbird communities. Agric. Ecosyst. Environ., 94: 17-29.

Farjalla VF, Amado AM, Laquê T, Faria BM, Esteves FA (2004). Present knowledge and perspectives in the study of planktonic bacteria in the Restinga lagoons of Jurubatiba. In: Rocha CFD, Esteves FA, Scarano FR (Org). Long time research program in the

Jurubatiba Restinga: Ecology, Natural History and Conservation. São Carlos: RiMa., 255-272.

Fernando CH (1956). The fish fauna of paddy fields and small irrigation ditches in the western lowlands of Ceylon; and a bibliography of references to fish in paddy fields. Ceylon J. Sci., 7: 223-227.

Fernando CH (1977). Investigations on the aquatic fauna of tropical rice fields with special reference to South-East-Asia. Geo-Eco-Trop., 3: 169-188.

Fernando CH, Furtado JI, Lim RP (1979). Aquatic fauna of the world's rice fields. Wallaceana Supplement Kuala Lumpur., 2: 1-105.

Fernando CH (1993) A bibliography of references to rice field aquatic fauna, their ecology and rice-fish culture. SUNY Geneseo - University of Waterloo, Geneseo N. Y., p. 110

Fernando CH (1995). Rice fields are aquatic, semi-aquatic, terrestrial and agricultural: A complex and questionable limnology. In: K.H. Timotius & F. Goltenboth (eds.), Tropic. limnol., 1: 121-148.

Fernando CH (1996). Ecology of rice fields and its bearing on fisheries and fish culture. In: S. S. de Silva (Ed.). Perspectives in Asian fisheries, pp. 217-237.

Fernando CH (2005) Rice field limnology and applied ecology. In: Fernando, C. H., Göltenboth, F. and Margraf, J. (ed.) Aquatic ecology of rice fields: a global perspective. Volumes Publishing, Ontario, pp. 71-117.

Figueredo CC and Gianini A (2005). Ecological interactions between Nile tilapia (*Oreochromis niloticus*, L.) and the phytoplanktonic community of the Furnas Reservoir (Brazil). Freshwater Biol. 50: 1391-1403.

Fukushima M, Takamura N, Sun L, Kagawa M, Matsushige K, Xie P (1999). Changes in the plankton community following introduction of filter-feeding planktivorous fish. Freshw. Biol. 42: 719-735.

Garcia AM, Bemvenuti MA, Vieira JP, Marques DMLM, Burns MDM, Moresco A, Condini,MV (2006). Checklist comparison and dominance patterns of the fish fauna at Taim Wetland, South Brazil. Neotropical Ichthyol., 2(4): 261-268.

Gazulha V (2004). Zooplankton community associated to wetlands and an internal lagoon in the Taim Hydrological System, Rio Grande do Sul, Brasil. Dissertação (Mestrado em Ecologia, Universidade Federal do Rio Grande do Sul), p. 127.

Granéli W, Lindell M, de Faria BM, Esteves FA (1998). Photo-production of dissolved inorganic carbon in temperate and tropical lakes - dependence on wavelength band and dissolved organic carbon concentration. Biogeochem., 43: 175-195.

Halwart M (1993) Fish in rice fields. In: P.P. Milan & S. Margraf (eds.) Annals of tropical research. Special issue on ecology VISCA-GTZ ecology program. Philippine freshwater ecosystems.

Halwart M (1994). Fish as biocontrol agents in rice. The potential of Common carp *Cyprinus carpio* (L.) and Nile tilapia *Oreochromis niloticus* (L.). Margraf Verlag, Weikersheim, p.169.

Heckman CW (1979). Rice field ecology in Northeastern Thailand. Monographiae Biol., 34: 1-228, Dr. W. Junk Publishers, The Hague.

Jespersen AM, Christoffersen K (1987) Measurements of chlorophyll-a from phytoplankton using ethanol as extraction solvent. Arch Hydrobiol., 109(3): 445-454.

Kobayashi T, DS Ryder, G Gordon, I Shannon, T Ingleton, M Carpenter, SJ Jacobs (2009). Short-term response of nutrients, carbon and planktonic microbial communities to floodplain wetland inundation. Aqua. Ecol.**,** 43: 843-858.

Kottek M, J Grieser, C Beck, B Rudolf, F Rubel (2006). World Map of the Köppen-Geiger climate classification updated. Meteorologische Zeitschrift., 15: 259-263.

Lai HC, Chua TE (1980). Limnological features of the Muda and Pedu reservoirs with an observation on their sustainability for fish culture. pp. 132-147. In: Biological Productivity in Muda-Pedu Reservoir and Canal Zone. Z.M. Ali [Editor].

Lazzaro X (1987). A review of planktivorous fishes: their evolution, feeding behaviours, and impacts. Hydrobiol., 145: 97-167.

Lazzaro X, Drenner RW, Stein RA (1992). Planktivores and plankton dynamics: effects of fish biomass and planktivore type. Can. J. Fish. Aquat. Sci., 49*:* 1466-1473.

Lazzaro X, Bouvy M, Ribeiro-Filho RA, Oliviera VS, Sales LT, Vasconcelos ARM, Mata MR (2003). Do fish regulate phytoplankton in shallow eutrophic Northeast Brazilian reservoirs. Freshwater Biol. 48: 649-668.

Lawler SP (2001). Rice fields as temporary wetlands: a review. Israel J. Zool., 47: 513 - 528.

Mackereth FJH, Heron J, Talling JF (1989). Water analysis: some revised methods for limnologists. 2nd ed. Freshwater Biological Association, Ambleside. p. 120.

Malley DF, Lawrence SG, Maciver MA, Findlay WJ (1989). Range of variation in estimates of dry weight for planktonic Crustacea and Rotifera from temperate North American Lakes. Can Tech Report Fish Aqua. Sci, p.1666.

McCune B, Mefford MJ (1999). PC-ORD. Multivariate analysis of ecological data, Version 4.10. MjM Software Design, Oregon. P. 237.

Nandini S, Sarma SSS (2007). Effect of algal and animal diets on life history of the freshwater copepod *Eucyclops serrulatus* (Fisher, 1851). Aquat. Ecol., 41: 75-74.

Reynolds CS (1997). Vegetation process in the pelagic: a model for ecosystem theory. In: Kinne O. (ed.), Excellence in Ecology. ECI, Oldendorf. p. 371.

Reynolds CS (2006). Ecology of Phytoplankton. Cambridge University Press, Cambridge, p. 535.

Roger PA (1996). Biology and management of the floodwater ecosystem in rice fields. International Rice Research Institute, P.O. Box 933. Manila 1029, Philippines, p. 250.

Ruttner-Kolisko A (1977). Suggestions for biomass calculations of plankton rotifers. Arch Hydrobiol Beih Ergebn Limnol., 8:71-76.

Shibayama H (2001). Weeds and weed management in rice production in Japan. Weed Biol. Manage., 1: 53-60.

Starling FLRM, Rocha AJA (1990). Experimental study of the impacts of planktivorous fishes on plankton community and eutrophication of tropical Brazilian reservoir. Hydrobiologia 200/ 201: 581-591.

Starling FLRM (1993). Control of eutrophication by silver carp (*Hypophthalmichthys molitrix*) in the tropical Paranoá Reservoir (Brasília, Brazil): a mesocosm experiment. Hydrobiol., 257: 143-152.

Starling F Beveridge M, Lazzaro X, Baird D (1998). Silver carp biomass effects on the plankton community and its use for improving water quality in Paranoá Reservoir (Brazil). Int. Rev. Hydrobiol., 83: 499-507.

Strome DJ, Miller MC (1978). Photolytic changes in dissolved humic substances. Ver Int Verein Theoret Angew Limnol., 20: 1248-1254.

Vakkilainen K, Kairesalo T, Hietala J, Balayla DM, Cares E, Van De Bund WJ, Van Donk E, Fernandez-Alaez M, Gyllstro M, Hansson LA, Miracle MR, Moss B, Romo S, Rueda J, Stephen D (2004). Response of zooplankton to nutrient enrichment and fish in shallow lakes: A pan-European mesocosm experiment. Freshwater Biol., 49: 1619-1632.

Wetzel RG (2001). Limnology: Lake and River Ecosystems. 3rd ed. San Diego: Academic Press. 1006p.

Williams DD (1987). The Ecology of Temporary Waters. Portland: Timber Press. p. 205.

Williams AE, Moss B (2003). Effects of different fish species and biomass on plankton interactions in a shallow lake. Hydrobiol., 491: 331-346.