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Trophic state and water turn-over time in six choked coastal lagoons in Brazil

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Abstract. Comparison of total phosphorus and chlorophyll-a concentration, nutrient loading, and water turn-over time in six shallow choked lagoons along the coast of the state of Rio de Janeiro, Brazil, established that water turn-over time is related to the trophic state of the lagoons with additional anthropogenic nutrient loading affecting this relationship. Turn-over time was calculated as a flushing half-life from rainfall, evaporation, runoff, and tidal exchange data, and trophic state was calculated from the quantity and quality of dissolved inorganic nutrients, total phosphorus, and chlorophyll-a standing stock. Flushing half-life of the lagoons ranged between 1 and 27 days, annual phosphorus areal loading from 3 to 18 mg $m^{-2}d^{-1}$, and chlorophyll-a standing stock from 6 to 160 mg m^{-2}.

Introduction

Human pressure from urbanization is increasingly affecting the natural habitat of lagoons along the coast of the state of Rio de Janeiro, Brazil. Artisinal fishing and recreation are now being impacted by uncontrolled effluent discharge into the lagoons and changing land usage in the drainage basins. As a result, fish kills and proliferations of benthic macroalgae are now frequent phenomena. Concern about water quality has only recently promoted the implementation of baseline studies and management strategies for these habitats. Sporadic water quality monitoring has been carried out since the late 1970's (FEEMA 1980, 1984, 1987 & 1988) and consistent process-orientated studies on pelagic and benthic primary production, organic matter mineralization, nutrient exchange across the sediment-water interface, mass balance of biogenic elements, and assessments of fisheries yields since the mid 1980's (Knoppers & Moreira 1988; Machado & Knoppers 1988; Barroso 1989; Carmouze et al. 1991, this issue; Costa-Moreira 1989; Knoppers et al. 1989; Knoppers & Moreira 1990; Knoppers et al. 1990). In contrast, studies on nutrient loading and hydrology (Kjerfve et al. 1990) have been neglected.

In spite of the paucity of information for some of the lagoons, the available data permit a comparison of basic physical and chemical features. We have investigated the relationship between water turn-over time and trophic state, the latter based on nutrient loading and concentrations of total phosphorus and chlorophyll-a in six shallow lagoons along the tropical coast east of Rio de Janeiro. We will show that trophic state is related to water turn-over time in the lagoons and that anthropogenic nutrient loading affects the relationship.

Lagoon description

The Fluminense coastline between the cities of Niterói and Cabo Frio (lat. 23°S and lon. 43°W) in the state of Rio de Janeiro, Brazil, encompasses dozens of lagoons which range from 0.5 to 270 km^2 (Fig. 1). They have mean depths of between 1 and 2 m, lie parallel to the coastline, and are classified as *choked* systems according to the scheme proposed by Kjerfve (1986). They are characterized by a single narrow connection and restricted water exchange with the sea, and the ocean tide is largely eliminated within the entrance canal (Kjerfve & Magill 1988; Kjerfve & Knoppers 1991).

We considered three lagoon systems, each consisting of one interconnected interior and one exterior lagoon. Only the exterior lagoons have direct access to the sea via a narrow tidal channel (Fig. 1). The Itaipu system consists of L. Piratininga (interior) and L. Itaipu (exterior), the Maricá system of L. Maricá (interior) and L. Guarapina (exterior), and the Saquarema system of L. Urussanga (interior) and L. Fora (exterior). The drainage basins of Piratininga, Itaipu, Maricá, and Fora lagoons are urbanized, whereas Guarapina and Urussanga lagoons are largely rural.

Physiographic features, annual rainfall and evaporation, runoff ratios, and tidal ranges for the six lagoons are presented in Table 1. The cumulative areas and volumes of the lagoon systems represent the sum of the individual lagoons plus intermediate lagoons of the systems omitted here. A climatic gradient exists between the lagoons with higher precipitation occurring to the west. Thus, the Itaipu system receives significantly higher rainfall than the Saquarema system. The tidal influence is greater in L. Itaipu, whereas the tidal range in the other exterior lagoons is less than

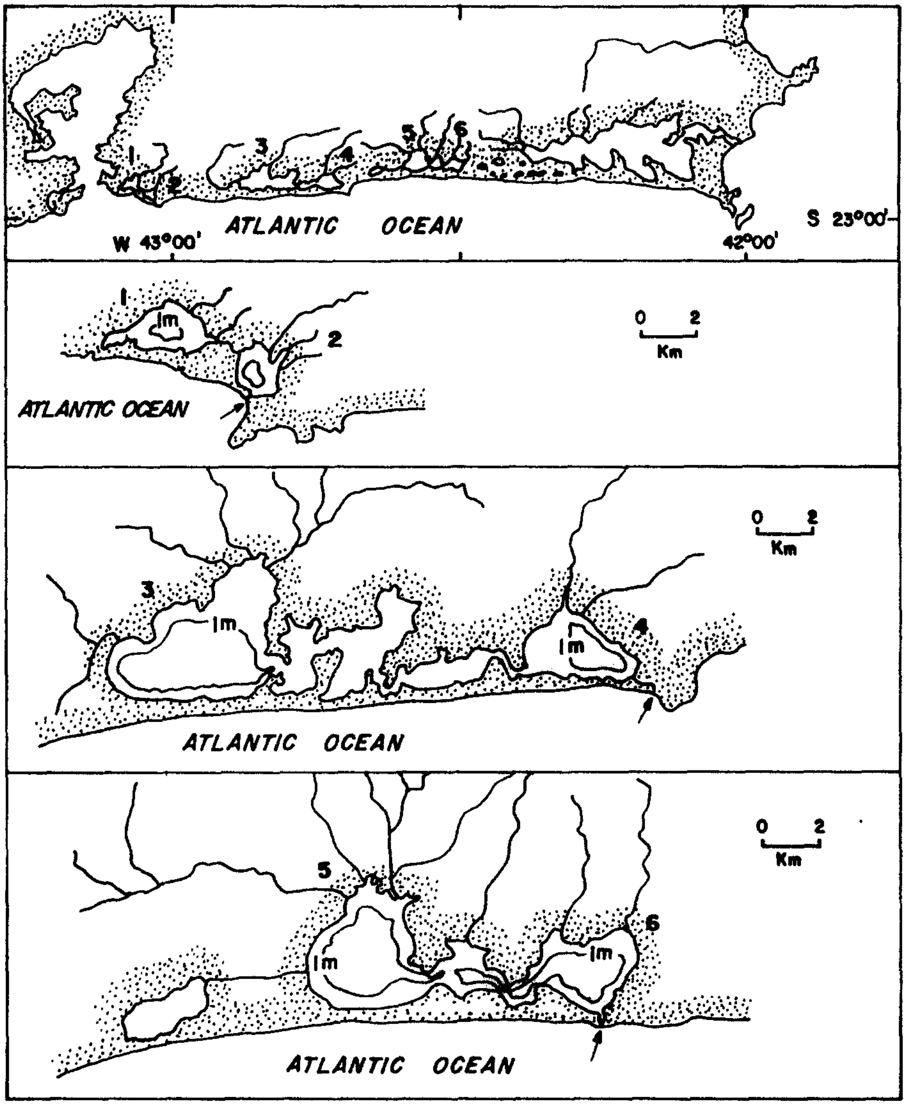

Fig. 1. The Fluminense coast of the state of Rio de Janeiro with (1) L. Piratininga, (2) L. Itaipu, (3) L. Maricá, (4) L. Guarapina, (5) L. Urussanga, and (6) L. Fora.

0.04 m and less than 0.01 m in all the interior lagoons. The similarity in physiographic setting and primary producers in the lagoons along the Fluminense coast allow for a functional comparison. With the exception of L. Piratininga, which is dominated by primary production from benthic macroalgae (*Charophytae* spp.), the remaining lagoons are dominated by phytoplankton production. Mean annual primary production is approximately 400 g C $m^{-2}y^{-1}$ in the Saquarema system, 324—412 g C $m^{-2}y^{-1}$ in L. Guarapina (Machado & Knoppers 1988; Moreira 1989), and 800 g C $m^{-2}y^{-1}$ in L. Piratininga.

Calculation of water turn-over time

In quantifying the flushing of coastal lagoons, we adopted the concept of flushing half-life ($T_{50\%}$ days) or the time that it takes to replace half of the lagoon water volume as the optimum measure of water turn-over time. We assumed complete mixing occurring rapidly relative to the flushing half-life, a reasonable assumption for choked lagoons, where turn-over time is long. Assuming first order kinetics, if V denotes the volume of water in the lagoon, t time, and κ a rate constant, we may write

$$\frac{\mathrm{d}V}{\mathrm{d}t} = -\kappa V \tag{1}$$

(Pritchard 1961) which can be integrated from $t = 0$ when the lagoon volume was V_0 to a new time, $T_{50\%}$, when the total water volume is the same but only 50% of the original water parcels remain inside the lagoon, or when $V_{\mathrm{new}}/V_0 = 0.50$. It follows that

$$T_{50\%} = 0.69/\kappa \tag{2}$$

Flushing in coastal lagoons depends on a combination of factors of varying importance. Most important tides, runoff, and the difference between rainfall and evaporation.

The tidal prism represents the new tidal water entering the lagoon every flooding tide. We will assume that this water did not exit from the lagoon during the previous ebb tide, an assumption which is quite reasonable in the case of the Fluminense lagoons, where the littoral currents are strong. Since the Fluminense tide is semidiurnal, we express the tidal exchange, Q_T as

$$Q_T = A_L \Delta h \left[\frac{24.00}{12.42} \right] \tag{3}$$

where Δh is the mean tidal range and A_L is the water covered area of each individual lagoon. A_L does not change appreciably between high and low tides because of the small tidal ranges, but are often appreciably different seasonally as a result of the runoff conditions.

In the absence of direct runoff measurements, we estimated the runoff into each lagoon from the runoff ratio, $\Delta f/r$, where

$$\frac{\Delta f}{r} e^{\left[\frac{-E_0}{r}\right]} \tag{4}$$

where Δf is annual runoff, r is the annual rainfall, and E_0 is potential evapotranspiration, which is a function of air temperature (Holland 1978; Kjerfve 1990). We calculated the daily runoff into each lagoon, Q_R as

$$Q_R = A_B \left[\frac{\Delta f}{r}\right] \left[\frac{r}{365}\right] \tag{5}$$

where A_B is the area of the effective drainage basin. It should be noted that for the interior lagoons, e.g. L. Piratininga, L. Maricá, and L. Urussanga, A_B is the area draining directly into the lagoon. However, for the exterior lagoons, e.g. L. Itaipu, L. Guarapina, and L. Fora, A_B is the total lagoon system drainage area which includes all interior drainage areas as this water must also pass through the exterior lagoon before exiting to the sea.

For most of the Fluminense lagoons, the direct rainfall on and evaporation from the lagoon surface are approximately in balance (Table 1). However, a slight imbalance might contribute to the lagoon flushing. We calculated this contribution, Q_E, as

$$Q_E = A_L \frac{|r - e|}{365} \tag{6}$$

Table 1. Calculation of flushing half-life for six Fluminense coastal lagoons.

Lagoon	A_L km^2	A_B km^2	V km^3	Δh m	r m	e m	$\Delta f/r$ —	s ppt
Piratininga	3	22	0.002	0.01	1.4	1.3	0.2	3
Itaipu	2	45	0.002	0.30	1.4	1.3	0.2	30
Maricá	17	215	0.021	0.01	1.3	1.3	0.2	1
Guarapina	7	350	0.007	0.03	1.3	1.3	0.2	07
Saquarema:								
Urussanga	13	185	0.014	0.01	1.3	1.3	0.2	1
Flora	7	232	0.007	0.04	1.1	1.3	0.2	20

where e is the annual evaporation rate (Harbeck 1962; Kjerfve 1990), based on wind speed data and the size of the lagoon. The absolute sign is necessitated by the fact that both rainfall and evaporation contribute positively to the flushing of the lagoon. Whereas excess rainfall mixes and exits through the canal, evaporation is lost through the surface but is replaced by new water entering from the entrance canal.

The rate constant κ represents the fraction of lagoon water volume replaced each day as a result of tidal exchange, freshwater runoff, and the rainfall-evaporation balance, and

$$\kappa = \frac{[Q_T + Q_R + Q_E]}{V} \tag{7}$$

The data used for our calculations are presented in Table 1 and the resulting flushing half-life for each lagoon is listed in Table 2, where data on rainfall, evaporation, wind speed, and water level changes for the lagoons, were furnished by the Instituto de Meteorologia (Sixth District), Rio de Janeiro, and Superintendência Estadual de Rios e Lagoas (SERLA).

Determination of nutrient loading

The mean annual concentrations presented (Table 3) for dissolved inorganic nutrients, i.e. nitrate, nitrite, ammonia, and orthophosphate, and total phosphorus (TP) and chlorophyll-a (Chl-a), are based on approximately fortnightly sampling over an annual cycle from central stations in the lagoons and in the channels connecting the lagoons to the sea. Sampling was done at either two or three depths. Sampling in Guarapina lagoon was conducted in 1985—1986 (Machado & Knoppers 1988; Moreira 1988; Knoppers & Moreira 1990) and in Piratininga, Itaipu, Urussanga and Fora in 1988—1989 (Costa-Moreira 1989; Carneiro et al. 1990; Knoppers et al. 1990). Standard methods were selected and are described in the above references. A consistent data set for L. Maricá does not exist. We thus opted to present concentration ranges from sporadic sampling (FEEMA 1980, 1984, 1987 & 1988). Analyses for nutrients, total phosphorus, and chlorophyll-a were conducted according to standard methods (Strickland & Parsons 1972; Grasshoff et al. 1983). Because of the high suspended load in the lagoons, water samples were filtered prior to nutrient analyses and, on some occasions, particularly in L. Piratininga, effluent dilution was necessary.

We monitored, either fortnightly or monthly, fresh-water flux into the lagoons and the concentration of nutrients and total phosphorus in the main two or three tributaries to each lagoon, and next, we calculated the annual nutrient loading in a step-wise fashion for each sampling occasion. Since tidal currents were too small to measure, we could adopt a simplified technique for calculating fluxes. We averaged the cross-multiplied in situ measured water flux and constituent concentration to obtain an average annual constituent stream input. For each lagoon, the total loading was calculated as the sum of the stream loads, but in the case of the exterior lagoons, the load from the interior lagoons were also added. The measured nutrient load was adjusted by a factor, corresponding to the ratio between the computed (from Eq. 4) and measured runoff to account for those streams that were not monitored. We found close correspondence between the two values, although the computed runoff systematically was 20—30% greater than the measured runoff. The resulting total riverine load and areal loading for each lagoon is shown in Table 4.

Results

The interior lagoons (Table 2) exhibit the longest flushing half-life. For example, we calculated L. Maricá to have a 27-day flushing half-life because of the great distance from the sea. The exterior lagoons, in contrast, have flushing half-lives as short as 1—7 days. Although the tidal water level fluctuations are small in the lagoons, tidal exchange is still a major factor in determining the flushing half-life. Although L. Itaipu is tidally dominated, tidal influence on L. Piratininga is dampened by the 2.4 km long, narrow channel connecting the two lagoons. Similarly, tidal exchange between L. Guarapina and L. Maricá, on the one hand, and L. Urussanga and L. Fora, on the other, is dampened by intermediate lagoons and channels.

The exterior lagoons, L. Guarapina and L. Fora have similar tidal characteristics and flushing half-lives, but there is a qualitative difference in the

Table 2. Calculation of flushing half-life and water exchanges due to tide, runoff, and rainfall-evaporation balance.

Lagoon	Q_T	Q_R (10 m^3 d^{-1})	Q_E	κ d^{-1}	$T_{50\%}$ days
Piratininga	58	17	1	0.04	16
Itaipu	1159	35	1	0.60	1
Maricá	329	153	0	0.02	27
Guarapina	406	249	0	0.09	7
Saquarema:					
Urussanga	251	122	4	0.03	23
Fora	541	127	6	0.10	6

nature of the tidal exchange induced by the configuration of the tidal channels. In L. Guarapina, the channel is 1.4 km long and permanent, whereas in L. Urussanga the channel is short and ephemeral, closing seasonally by active sediment processes. For this reason, tidal exchange is continuous in L. Guarapina but seasonal in L. Fora, and more efficient when the channel is open.

In all cases, nutrient and chlorophyll-a concentrations and the ratio of total inorganic nitrogen to total inorganic phosphorus (TIN/TIP) are far greater in L. Piratininga than in the other lagoons (Table 3). The major fraction of matter in L. Piratininga is stored in sea weed. In contrast, the other five lagoons are phytoplankton-based with nutrient concentrations less than half of the L. Piratininga values. Of the phytoplankton-based lagoons, L. Guarapina exhibits the lowest and L. Itaipu the highest nutrient levels. Compared to the Saquarema and Maricá-Guarapina systems, the Piratininga-Itaipu system exhibits the largest gradients in chemical parameters (Table 3).

For all lagoons, ammonia was the major component ($>50\%$) of TIN with major sources in L. Urussanga and L. Guarapina being the bottom and, in L. Piratininga being human effluents and the algal banks. The N/P ratio was comparable for all lagoons and indicated a trend towards nitrogen limitation. TP and chlorophyll-a concentrations (Fig. 2) are closely related to each other, and the large y-axis intercept implies that a large fraction of TP is of detrital origin. Zooplankton biomass is only a minor contribution.

Mean annual loading of DIP, TIN, and TP, expressed in kg d^{-1}, and the computed areal lagoon loading, in mg $m^{-2}d^{-1}$, is presented in Table 4. The

Table 3. Annual average concentrations (mg m^{-2}) of dissolved inorganic phosphate (DIP), dissolved inorganic nitrogen (DIN = NH_4^+-N +NO_2^--N + NO_3^-N), total phosphorus (TP), and chlorophyll-a (Chl-a) in the six Fluminense lagoons plus the number (*n*) of field determinations and the ratio of dissolved inorganic nitrogen-to-phosphorus by weight, N/P, and the trophic state.

Lagoon	DIP	DIN	TP	Chl-a	*n*	N/P	State
Piratininga	78	458	350	160	22	6/1	Hypertrophic
Itaipu	22	160	91	6	14	7/1	Mesotrophic
Maricá	–	39	270	87	8	–	Eutrophic
Guarapina	11	25	158	43	22	2/1	Eutrophic
Saquarema:							
Urussanga	19	52	201	50	19	3/1	Eutrophic
Fora	19	52	170	28	20	3/1	Eutrophic

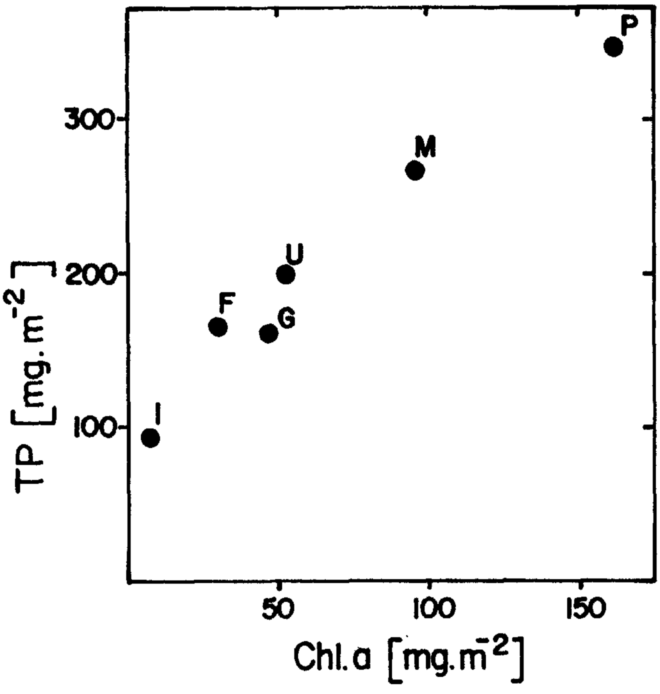

Fig. 2. Scatter diagram of total phosphorus (TP) vs. chlorophyll-a (Chl-a) for the six Fluminense lagoons.

Table 4. Riverine loading and areal lagoon loading of dissolved inorganic phosphate (DIP), dissolved inorganic nitrogen (DIN = NH_4^+-N + NO_2^--N + NO_3^-N), total phosphorus (TP) in five of the six Fluminense lagoons, and the number (*n*) of field determinations. The TP loading for L. Maricá was estimated independently based on the population and phosphorus loading.

Lagoon	*n*	DIP	TP	DIN	DIP	TP	DIN
			Loading (kg d^{-1})			Areal load (mg m^{-2} d^{-1})	
Piratininga	35	13	32	59	4	11	21
Itaipu	12	11	35	75	5	18	37
Maricá	—	—	81	—	—	6	—
Guarapina	53	8	31	81	1	5	12
Saquarema:							
Urussanga	16	8	40	9	1	3	1
Fora	15	11	86	39	2	12	6

highest areal nutrient loading occurs in L. Itaipu, because L. Itaipu receives much of the human effluent discharge which enters L. Piratininga and because L. Itaipu measures only 1 km^2. The lagoons receive a comparable load within a factor of three. Loading from the L. Urussanga and L. Guarapina drainage basins is minimal and conditions closely resemble a natural state. However, L. Guarapina does receive a considerable load from its adjacent interior lagoons (L. Padre, L. Barra, and L. Maricá). The source of the high TIN load (ammonia) in L. Guarapina is primarily due to decomposition of benthic algae of the species *Cladophora* in L. Padre. The intermediate lagoons change seasonally their role in the transfer of matter and nutrients between L. Maricá and L. Guarapina, alternately they function as a filter and alternately as an internal recycling source by releasing nutrients. Autotrophic biomass, i.e. chlorophyll-a is related to the areal DIP and TIN loading (Figs 3 & 4). L. Itaipu, however, is an exception with a high nutrient load and low autotrophic biomass.

We were not able to compile information on nutrient loading for L. Maricá because of scarcity of data. However, an estimate based on the per capital load of phosphorus from the population in the city of Maricá (38,500) suggests that this lagoon receives more human effluent discharge

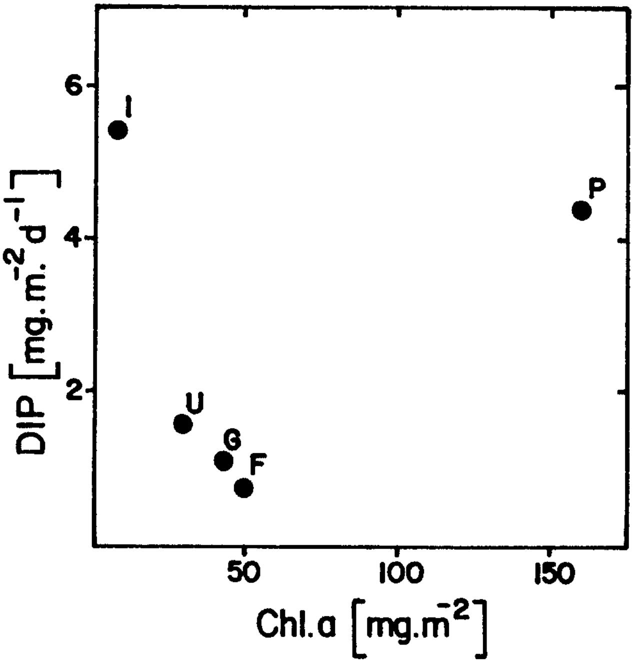

Fig. 3. Scatter diagram of areal dissolved inorganic phosphorus (DIP) vs. chlorophyll-a (Chl-a) for the six Fluminense lagoons.

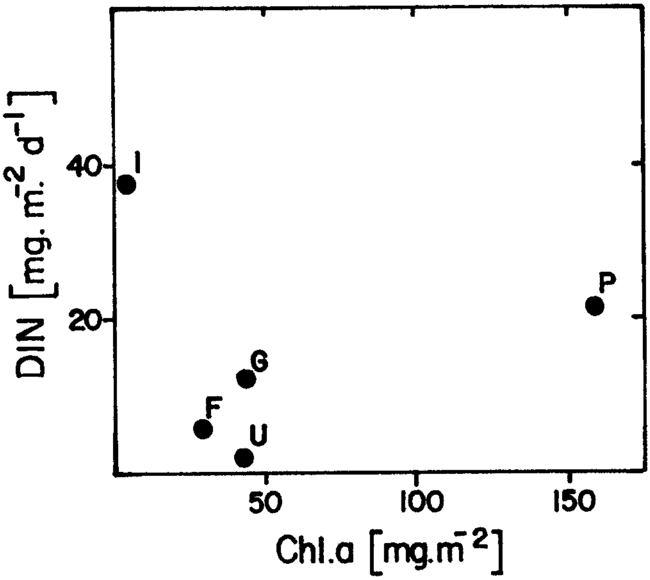

Fig. 4. Scatter diagram of areal dissolved inorganic nitrogen (DIN) load vs. chlorophyll-a (Chl-a) for the six Fluminense lagoons.

than the other lagoons. Per capita loading in L. Maricá was estimated from data on population density obtained by the local public health organization with a loading factor of 3 g P per capita d^{-1} (FEEMA 1988) and 70% of the population contributing to the lagoon effluent (FEEMA 1987). We also made this computation for the other five lagoons, with results within 20% of measured TP values with exception of L. Fora.

Discussion

Studies of trophic state (TS) serve to assess water quality and degree of nourishment and maturity of aquatic systems. Such studies are useful in establishing monitoring needs, represent a first step in developing management policies, and form the basis for modeling of environmental eutrophication. Of the many available methods used for TS-ranking (Carlsson 1977; Lambou et al. 1983), we apply the simplest method, utilizing total phosphorus and chlorophyll-a, according to the ranking system (Rast & Holland 1988). However, it must be borne in mind that most of the concepts and standards have been developed for lakes and reservoirs, and their transfer to coastal lagoons may be problematic. For example, coastal lagoons tend more towards nitrogen limitation than phosphorus limitation

(Nixon 1982), thus making total phosphorus a less suitable standard. However, the role of nitrogen fixation as an additional nitrogen source is a much over-looked process in tropical coastal lagoons. A review of the effects of nutrient enrichment and limitation for fresh and marine systems, has, on the other hand, shown that the extent and severity of nitrogen limitation in marine systems has not yet been resolved (Hecky & Kilham 1988).

The application of total nitrogen as a TS standard is not well documented for lagoons (Nixon 1982), but is nevertheless desirable, because many aquatic systems are subject to an increase in effluent discharge with low N:P ratios and are thus driven towards nitrogen limitation. In spite of this fact, the application of TP and chlorophyll-a for TS-ranking in the Fluminense lagoons was feasible. We opted to use the average annual concentrations for our TS determination, rather than peak summer values commonly applied to determine TS in lakes. We did so because the lagoons do not demonstrate an equally pronounced seasonality.

Using both total phosphorus and chlorophyll-a concentrations as TS indices demonstrates that the six lagoons are mostly eutrophic. L. Itaipu borders on mesotrophic, however, with the TP level indicating a eutrophic state, whereas chlorophyll-a indicates a mesotrophic state. This may be attributed to the high TP load from L. Piratininga and the high detrital TIP fraction by frequent resuspension of bottom materials by strong tidal currents. L. Piratininga, on the other hand, is permanently hypertrophic. Its shallow water depth, continuous effluent loading, and long flushing half-life are the reasons for the extensive algal banks which photosynthesize throughout the year. Although nutrient loading into L. Itaipu is higher than for L. Piratininga, rapid tidal dilution mitigates the effects of the large effluent loading.

With the exception of L. Piratininga, the total phosphorus and dissolved inorganic nutrient concentrations of the lagoons, are within the range of many tropical and sub-tropical lagoons with low to moderate effluent discharge, e.g. L. Conceição, Brazil (Knoppers et al. 1984), Harrington Sound, Bermuda (Bodungen et al. 1982), Mediterranean lagoons (Vaulot & Frisoni 1986), and some Venezuelan mexican lagoons (Mandelli 1981; Okuda 1981; Nixon 1982). In contrast, conditions in L. Piratininga, with high standing stock of benthic algae and heavy nutrient loading, is comparable to Venice Lagoon, Italy, and the Peel-Harvey system in Australia (McComb et al. 1981; Hodgkin & Birch 1982; Sfriso et al. 1988).

The flushing half-lives of the Fluminense lagoons range between 1 and 27 days. The interior lagoons are least affected by tidal exchange and display the longest half-lives. A comparison of our flushing times to results of other studies must be done with care because of different methods used to estimate flushing rates. We have adopted a measure of a flushing half-life analogous to the measures of LD-50 and half-lives of isotopes. Comparison of our estimates to published flushing times should therefore be with care to make sure that they are calculated analogously. Flushing rates have most often been calculated based on either (1) fresh water inflow or (2) tidal prism. We have attempted, however, to account simultaneously for the major processes affecting the water balance in computing the flushing rate, including freshwater inflow, tidal prism, rainfall, and evaporation. Data to allow a similar computation for other lagoons are scarce but have been reported for the Huizache-Caimanero system in Mexico (Moore & Slinn 1984), several Mediterranean lagoons (Vaulot & Frisoni 1986), and the Peel-Harvey system in Australia (Hodgkin & Birch 1982). These choked lagoons all have longer reported flushing times than the Fluminense lagoons although size and geomorphological conditions are similar. The Fluminense lagoons lack a pronounced dry-wet season cycle, and have more continuous fresh water inflow and tidal exchange. Nevertheless, they are all eutrophic, exhibit higher autotrophic biomass during the warm season and during periods with prolonged flushing half-life.

For the six Fluminense lagoons, there existed a clear relationship between flushing half-life and trophic state, based on TP and chlorophyll-a (Figs 5 & 6). The interior lagoons, i.e. L. Piratininga, L. Maricá, and L. Urussanga with the longest flushing half lives are also the best nourished lagoons. Although L. Fora has only a 6-day flushing half-life, it is also well nourished from human effluent discharge from the population of Saquarema (32,000). Scatter in the relationships is most evident for the interior lagoons where the composition of primary producers differ. If we only consider the phytoplankton based systems, thus discarding L. Piratininga, the relationships become much more evident.

In the case of the Fluminense lagoons, flushing half-life and nutrient loading is related to total phosphorus and chlorophyll-a content. To what extent this is a common feature of choked coastal lagoons in general is still difficult to assess. Empirical relationships of this kind have been well established for lakes (Vollenweider 1976; Schindler 1978; Schindler 1981). Similar trends in coastal lagoons have only been reported in five Mediterranean lagoons (Vaulot & Frisoni 1986). Other studies in lagoons and estuaries, aimed to link physiographic and hydrological features such as size, area-to-volume ratio, tidal exchange, and nutrient loading to autotrophic biomass and primary production, have yielded conflicting results (Jaworski 1981; Boynton et al. 1982; Welsh et al. 1982). For example, a comparative study (Welsh et al. 1982), including four estuaries

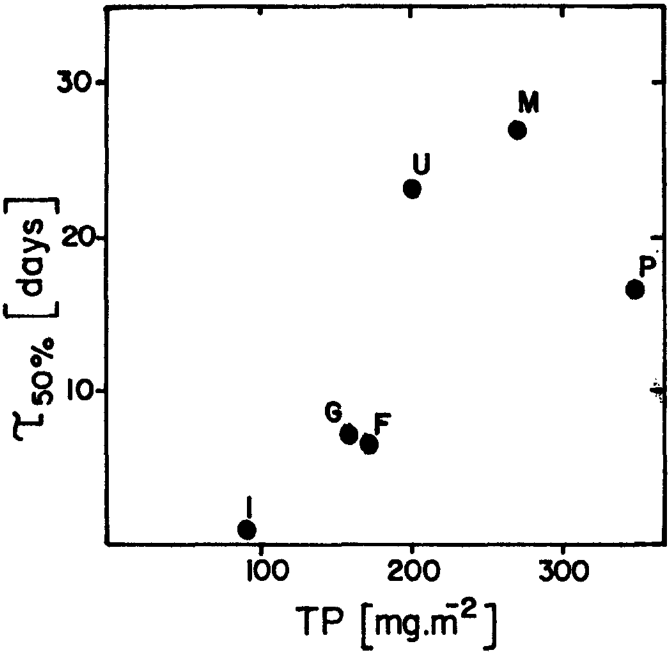

Fig. 5. Scatter diagram of flushing half-life ($T_{50\%}$) vs. total phosphorus (TP) for the six Fluminense lagoons. L. Piratininga does not fit the relationship as this is the only lagoon dominated by benthic macroalgae.

and five lagoons in New England, revealed a strong correlation between area-to-volume ratio, total production, benthic production, and benthic-to-pelagic production ratio, but links to other physical forcing functions were less significant.

Some reasons responsible for difficulties in relating physical processes (e.g. flushing) to biogeochemical factors (e.g. trophic state) in coastal lagoons are that:

- flushing or residence times are based on a single forcing function rather than the hydrological balance, which results in an underestimate of the flushing time and makes comparisons between studies difficult;
- lagoons are highly diverse natural systems, ranging from choked, restricted, to leaky types (Kjerfve 1986), and exhibit large differences in dominant physical processes; and
- lagoons alternately are either phytoplankton, seagrass, macro-algal, or micro-algal based systems.

This suggests, that pooling of systems in comparative studies, irrespective of differences in physical nature and predominance of autotrophic popula-

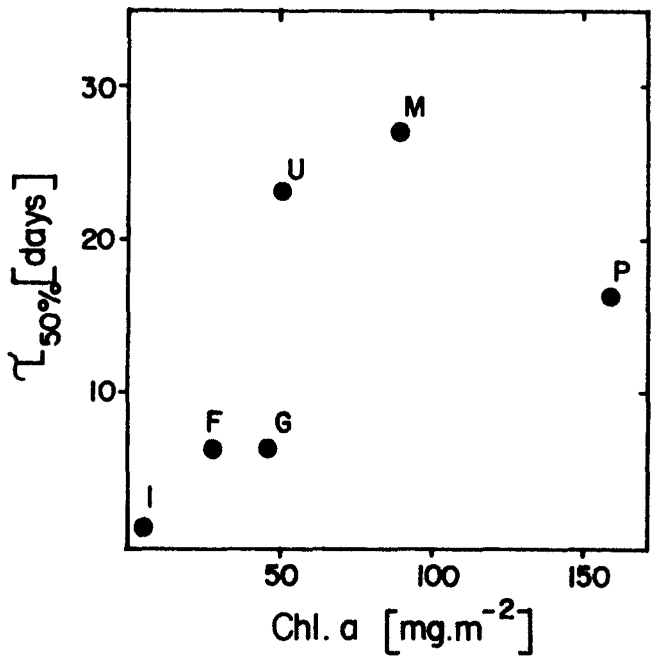

Fig. 6. Scatter diagram of flushing half-life ($T_{50\%}$) vs. chlorophyll-a (Chl-a) for the six Fluminense lagoons.

tions, is not ideal for establishing physical, chemical, and biological links. The present comparison of six choked coastal lagoons in Brazil yielded a clear relationship between flushing half-life and autotrophic biomass in the five phytoplankton based systems. Vaulot & Frisoni (1986) obtained similar results in comparing Mediterranean phytoplankton based lagoons. In our case, when we include L. Piratininga, i.e. a choked macroalgal based lagoon, the relationship is less distinct.

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