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TEMPERATURE AND HEAT BUDGET IN A FLOODPLAIN POND OF THE MIDDLE PARANA RIVER (ARGENTINA)

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ABSTRACT

Drago E.C. & A.R. Paira. 1987. Temperature and heat budget in a floodplain pond of the Middle Paraná River (Argentina). *Rev. Asoc. Cienc. Nat. Litoral 18* **(2)**: 193 – 201

Monthly water temperature data were taken for La Cuarentena pond and Paraná River, Argentina, over a two-year period. The data show that the pond is seasonally unstratified and that any stratifications are occasional and slight. However, strong stratifications were observed under floating macrophytes. The thermal regime is principally influenced by the basin morphology, air temperature, wind and floodwater. As a result of its temperature and circulation pattern, La Cuarentena pond can be classified as "continuous warm polymictic". The heat budget is about 3 000 cal cm^{-2}, with maximum heat content of 5 000 cal cm^{-2}. The heat budget for bottom sediments is about 1 100 cal cm^{-2}.

RESUMEN

Drago, E.C. y A.R. Paira. 1987. Temperatura y balance calórico en una laguna de inundación del río Paraná Medio (Argentina). *Rev. Asoc. Cienc. Nat. Litoral 18* **(2)**: 193 – 201 .

Durante un período de más de dos años, se obtuvieron datos de la temperatura del agua en la laguna La Cuarentena y en el río Paraná. Los datos han demostrado que la laguna no presenta estratificaciones estacionales, pero sí estratificaciones ocasionales y débiles. No obstante, fuertes gradientes térmicos han sido observados debajo de las macrófitas flotantes. El régimen térmico se halla influenciado principalmente por la morfología de la cubeta, la temperatura del aire, el viento y por las aguas de inundación. Como resultado de su temperatura y del tipo de circulación, La Cuarentena puede ser clasificada como una laguna "polimíctica cálida continua". Su balance calórico es de 3 000 cal cm^{-2}, con un contenido máximo de calor de 5 000 cal cm^{-2}. El balance calórico para los sedimentos de fonto es de 1 100 cal cm^{-2}.

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INTRODUCTION

The floodplain of the middle reach of the Paraná River with an area of 13 000 km^2, is a complex hydrosystem of lotic and lentic environments and wetlands. This fluvial ecosystem is strongly affected by the annual periods of high and low waters. The thousands of water bodies existing in the Middle Paraná valley, present great differences in forms and areas. According to their origin, the basins vary from circular to dendritic in shape with lengths between 50 m and 10 km, and depths from 0.5 m to over 6 m. These morphometric differences, the extent of connection between the ponds and the streams, and variation in the types and cover of the aquatic vegetation markedly affect the circulatory processes, resulting in different thermal structures.

The La Cuarentena pond (31° 42′ S – 60° 37′ W), near Santa Fe city (Argentina), was formed by the coupling of islands and channel bars (type 7: inter-bar pond)[4], by which it has a typical dendritic outline (Fig. 1; Table 1). The climate of the region is rainy temperate (CF w′ ah of the Koeppen classification)[10]. It is characterized by an annual mean temperature of 18.1 °C, and an annual average range of 45 °C, with mean temperature in the warmest month of 24.5 °C (January) and in the coldest month of 11.3 °C (July). Summers are hot, with maximum recorded temperatures of 44 °C, and 1 743 mm of annual rain. The prevailing wind directions are from NE, E and SE.

The data about temperature conditions and heat budget of La Cuarentena pond are presented. This water body has a direct connection with the main channel of the Paraná River and is free of aquatic vegetation, thus being a typical example of the largest ponds existing in the Paraná River valley. The information about the heat budget is the first contribution for the Paraná River drainage basin.

Table 1

Morphometric characteristics of La Cuarentena pond at mid-water level (Santa Fe, Argentina).

Area – A	(m^2)	2 745 000
Volume – V	(m^3)	4 880 000
Maximum depth – z_m	(m)	5
Mean depth – $\bar{z}$	(m)	1.78
Relative depth – Z_r	(°/o)	0.27
Length – l	(m)	5 300
Maximum breadth – b	(m)	1 550
Mean breadth – $\bar{b}$	(m)	520
Shore line – L	(m)	20 000
Development of shore line – D_L		3.4
Development of Volume – D_V		1.07
Fetch of major basin – F	(m)	2 700
Fetch of secondary basin – Fsb	(m)	1 700

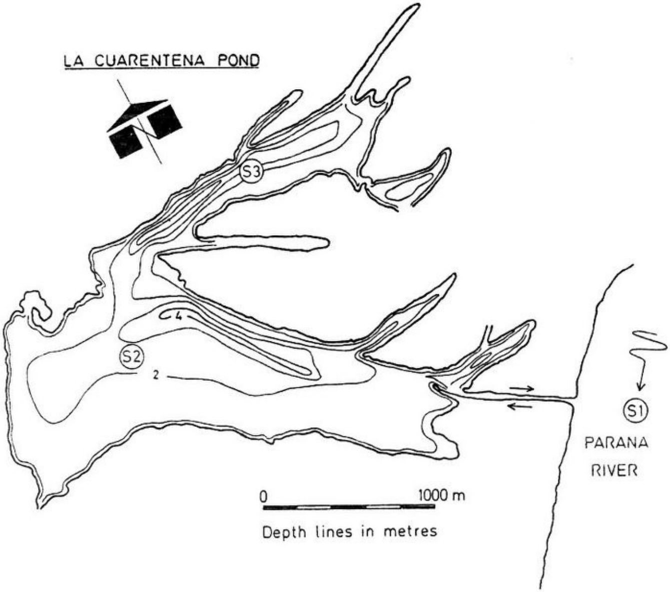

Fig. 1. Bathymetric map of La Cuarentena pond at mid-water level, showing the sampling stations.

MATERIAL AND METHODS

Observations were carried out monthy between July 1980 and August 1982 at two lacustrine sampling stations and at one station in the river (Fig. 1). The temperature measurements were made at 0.5 m intervals from the surface to bottom by means of a thermistor device reading to 0.1 °C. The temperature of the bottom sediments was measured with the same thermistor at a depth of 5 cm. Measurements were always carried out between 11.00 and 13.00 hours, since significant changes in water temperature were occurred over 24 h, particularly in the summer. The data of solar radiation and air temperature, were obtained from a meteorological station of INTA - Paraná (Entre Ríos Province, Argentina), located about 13 km from the pond.

The temperature soundings can be used to obtain the total heat content of the water body or the total change in heat content between any two dates of temperature measurement[6]. The daily heat budget was calculated from the expression:

$$\Theta_{bd} = (V \cdot T_w) / A_0,$$

where Θ_{bd} is the heat content for each measurement day (cal cm^{-2}), V is the volume of the pond (cm^3), T_w is the mean temperature of the water column (°C), and A_0 is the surface area of the pond (cm^2). The shallowness of the water body and the lack of a permanent thermal stratification gave the possibility of using that methodology [1,3,8,11,14,17].

The total annual heat budget (Θ_{ba})[8] is the difference in the amount of heat in the pond between the times of lowest and highest temperature. Calculations utilize the minimum temperature measured in winter and the maximum measured in summer.

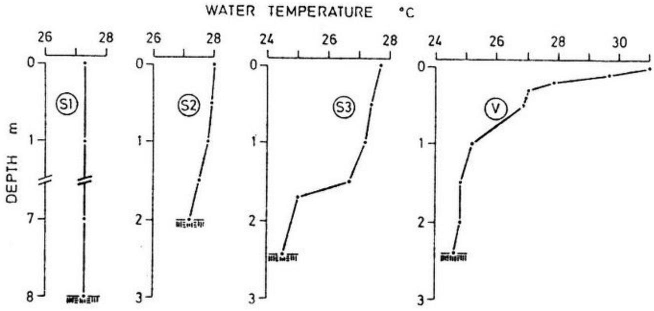

Fig. 2. Temperature profiles during spring calm weather (30-10-81), showing the characteristic homothermy in the river (S1), the slight stratification in the major basin (S2) and the strong stratifications in the secondary basin (S3) and near the shore under a floating meadow (V).

RESULTS AND DISCUSSION

Thermal conditions

The morphometric characteristics (mainly depth and fetch) together with the wind action and the lack of a vegetal cover prevent the establishment of a permanent vertical stratification. Nevertheless, during some sunny and warm days of spring and summer momentary temperature stratifications do occur (Fig. 2). The highest and lowest water temperatures measured during the study period were 20 °C and 11.5 °C. The maximum temperature in the river (30 °C), allow us to suggest that the pond waters sometimes would attain this level or even higher. In January 1983 Bonetto *et al.*[2] found a maximum temperature of 30 °C in an alluvial pond near Corrientes city (27° 30′ S; Argentina). In a coastal floating meadow we measured a temperature of 31 °C. In the central station of La Cuarentena pond at a depth of 2.5 m, the maximum difference between surface and bottom water was 0.8 °C (30-10-81). This small difference is a consequence of that site being continuously stirred by the winds (fetch = 2.7 km). In addition, the approximate coincidence between the lowest pond water level and the period of maximum wind stress lead to the destruction of any thermal stratification.

Roughly two-thirds of the time the surface water temperature of station 2 was somewhat higher than that of station 3, located in a secondary basin (Fig. 3), the difference reaching a maximum of 2 °C. Such difference results from the fact that the major basin of the pond is more directly influenced by the warmer river water, which can enter through a short channel. Although the secondary basin is always more isolated from the river influence, yet the strong entrance of river water during floods may destroy any temperature differences between the two stations. In addition, stronger stratifications were measured at station 3, because it is more sheltered from the wind action. As a result of its thermal behaviour La Cuarentena pond can be classified as "continuous warm polymictic" according to Lewis's classification[12]. This type of shallow water body is mixed daily, either in response to variation in wind stress or to loss of heat at night. The pond was stratified at most for a few days at a time during calm weather. There is no ice cover at any time.

Owing to general absence of stratification, the nearly continual mixing, and the direct hydrological connection with the river, we assumed that the response of the pond to atmospheric changes would be similar to that detected by Drago[5] for the adjacent Paraná River waters. The high correlations between surficial water temperatures and mean and maximum daily air temperatures, corresponding to an average of various days preceding the sampling date, enable us to examine this relationship. Thus, in waters

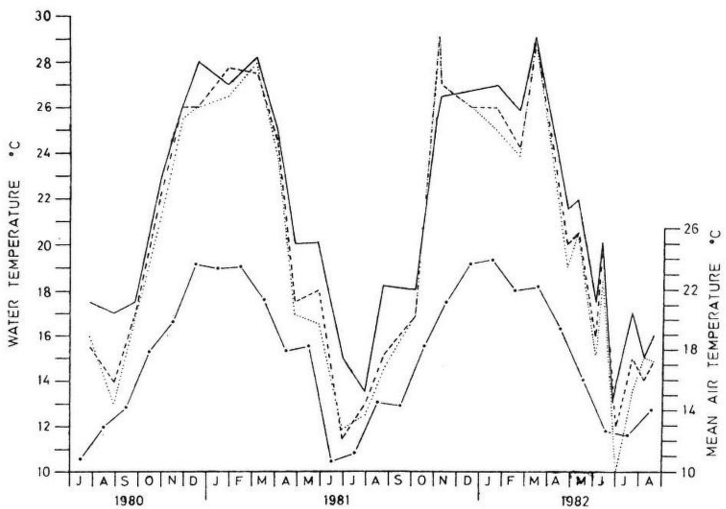

Fig. 3. Water temperature variations in the Paraná River S1 (————), and in the lacustrine stations S2 (– – – – – –) and S3 (. . . . . . .); mean monthly air temperatures (• ——— •).

like La Cuarentena pond, it is possible to predict the water temperature from the air temperatures. The equations are:

$$T_w = 2.103 + 1.042\ (\overline{Tad_{12}}),\ (r = 0.96,\ p < 0.001),\ \text{and} \quad (1)$$

$$T_w = 1.426 + 0.963\ (\overline{Tamax_{12}}),\ (r = 0.91,\ p < 0.001), \quad (2)$$

where T_w is the pond water temperature, $\overline{Tad_{12}}$ is the mean daily air temperature averaged over the previous twelve days, and $\overline{Tamax_{12}}$ is the average of maximum air temperatures during previous twelve days. None of the correlation coefficients was less than 0.89 for mean air daily temperatures and 0.84 for mean air maximum daily temperatures for periods of the previous thirty days (Figs. 4 and 5).

Usually both lentic and lotic waters showed similar variations, but during more than 70 o/o of the study period the river water temperature was higher than the pond water, because of the closer contact of the river waters with the atmosphere (Fig. 3).

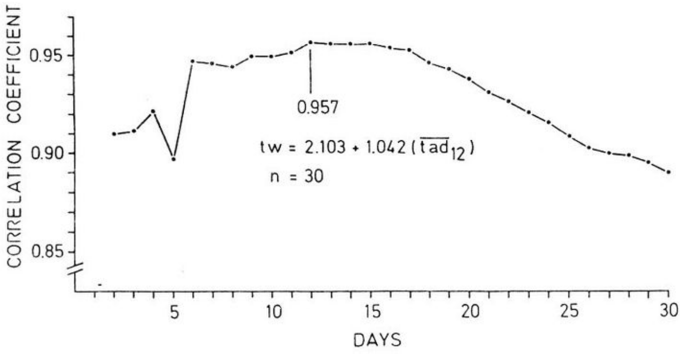

Fig. 4. Correlation coefficients showing the relationship between pond water temperature (tw) and the mean daily air temperature averaged between two and thirty days previous preceding the sampling date.

Heat budget

The total annual heat budget is the difference in the amount of heat stored between the times of lowest and highest temperature. In La Cuarentena pond the maximum summer heat content was 5 168 cal cm^{-2} and the minimun winter heat content 2 050 cal cm^{-2} for the complete period (July 1980 - August 1982). Thus, the total heat budget was 3 119 cal cm^{-2}. The heat budget of bottom sediments for the

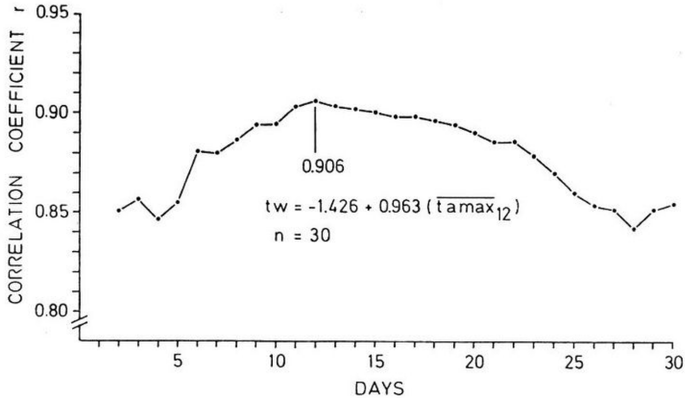

Fig. 5. Correlation coefficients showing the relationship between pond water temperature (tw) and the maximum daily air temperature averaged between two and thirty days previous preceding the sampling date.

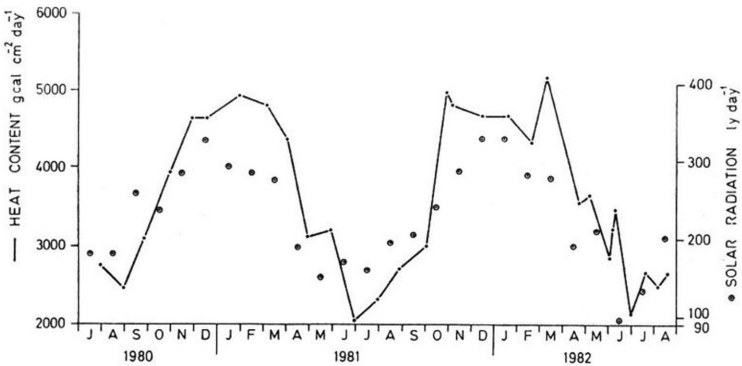

Fig. 6. Heat content variations in La Cuarentena pond and the relationship with the mean monthly values of solar radiation.

same period was 1 154 cal cm^{-2}, *i.e.*, about 37 o/o of the total heat budget. The heat budget for a single year is similar, being 2 896 cal cm^{-2} for 1981, derived from maximum and minimum heat contents of 4 990 cal cm^{-2} and 2 049 cal cm^{-2}.

The daily heat contents of the pond followed the expected seasonal pattern (Fig. 6). The maximum values occurred in spring-summer periods, depending on the weather conditions in these unstable seasons, and the minimum in winter. The form of the heat content curve roughly followed the form of the air temperature curve, except for the fast loss of heat content during the early fall (compare the Figs. 3 and 6). The maximum rate of heat storage occurs during the early spring.

CONCLUSIONS

The thermal structures of the floodplain ponds in the Middle Paraná River depend principally on the area, form and depth of the water body, fetch and degree of shelter of the sampling station, type and degree of cover of aquatic vegetation, and amount of connection between the main channel and its anabranches. In La Cuarentena pond, the sheltered station 3 is the one that exhibited temporary although remarkable temperature stratifications. Minimum temperature differences between surficial and bottom waters were always measured in the major basin, because of its shallower depth and because it is more influenced by the winds and by the entrance of river waters. Such ponds having great surface areas, shallow depths, lack of vegetation cover, and a direct connection with the river, are continually mixed vertically. Other water bodies, isolated from the stream and with a smaller surface area and having a cover of floating vegetation, can present different thermal conditions.

As a result of its temperature and circulation patterns, La Cuarentena pond can be classified as "continuous warm polymictic", according to Lewis's classification based on mixing[12]. Owing to those characteristics and for similar types of water bodies, it is possible to predict the temperature of pelagic waters from the air temperatures through the estimated equations (1) and (2). None of the correlation coefficients was less than 0.89 for mean air daily temperatures, and 0.84 for mean air maximum daily temperatures for periods of previous thirty days.

The heat contents followed the expected seasonal pattern, with maximum values in spring-summer period and minimum in winter. The annual heat budget for La Cuarentena pond is about 3 000 cal cm^{-2}, with maximum heat content of 5 000 cal cm^{-2} and minimum heat content of 2 000 cal cm^{-2}. The heat budget for bottom sediments is about 1 100 cal cm^{-2}, *i.e.*, 37 o/o of the total heat budget. These figures are comparable to those of other lentic environments of the world having similar morphometrical characteristics[3,7,8,13,17].

The annual heat budget of La Cuarentena pond is low, which may be attributed to many factors. The volume of water in the pond is small, particularly in comparison with the surface area. There is direct irradiation for long periods during the day, because a great part of the pond is not sheltered by trees. Energy, therefore, is lost because of this exposed situation and the wind stresses. Furthermore, the sediment laden and reddish-brown waters of the pond facilitate solar reflection. Previous studies[9,15,16] have shown that suspended sediment in surface waters scatters solar radiation and that the back-scattered radiation is rejected across the air-water interface as reflection. This loss of energy results in a lower surface temperature and a lower heat content of the entire pond. Further studies of this kind will be performed in La Cuarentena pond an other floodplain water bodies of the Middle Paraná River.

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