

Design and evaluation of benthic mesocosms for coastal lagoons

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ABSTRACT

We present the design of mesocosms built to run experiments in a coastal lagoon of the southern Atlantic Ocean, in Uruguay. Cylindrical mesocosms (1.7 m high, 2.26 m diameter) were built using supporting structures of iron grating (15 x 15 cm) to avoid damage from strong winds. The iron structures were still in good condition for over four years. Within the iron grating, four types of materials were tested for the walls. A single galvanized iron sheet, painted, and covered with thermic polyethylene on both sides proved to be the most suitable design under conditions of low water levels. This design remained in good conditions for more than 6 months. In the short and medium term, i.e. weeks to months, light, Secchi disk transparency, temperature and dissolved oxygen were similar inside and outside the mesocosms, indicating that the experimental set-up did not cause any artifacts. However, very short-term experiments may be affected by the water heating due to its confinement, while in the long-term, i.e. more than one year, the enclosures' walls suffer major deterioration. A wind-driven agitator was tested to simulate the water mixing within the enclosures. However, light penetration was highly reduced with the mixing system. Temperature profiles inside and outside the polyethylene enclosures showed that they were vertically mixed. Differences in dissolved oxygen concentration between surface and bottom within the enclosures as well as between enclosures and the lagoon were small.

Keywords: Mesocosms, limnocorrals, sediments, benthos, estuaries

RESUMEN

Se presenta el diseño de mesocosmos contruidos para realizar experimentos en lagunas costeras del océano Atlántico austral, en Uruguay. Se construyeron mesocosmos cilíndricos (1.7 m de altura y 2.26 m de diámetro), utilizando malla de hierro para la construcción (15 x 15 cm) como soporte para evitar el daño de los fuertes vientos. Estas estructuras se mantuvieron en buenas condiciones por más de cuatro años. Dentro de la malla se probaron 4 tipos de materiales para las paredes. El más apropiado cuando el nivel del agua era bajo, fue una simple chapa de hierro galvanizado, pintada y recubierta con polietileno térmico por ambos lados. Este diseño se mantuvo en buenas condiciones por más de 6 meses. A corto y mediano plazo, i.e. semanas a meses, la luz, la transparencia de disco de Secchi, la temperatura y el oxígeno disuelto fueron similares dentro y fuera de los mesocosmos, indicando que las estructuras no provocaban artefacto alguno. Sin embargo, los experimentos a muy corto plazo pueden ser afectados por el calentamiento del agua debido a su confinamiento, mientras que en el largo plazo, i.e. más de un año, las paredes sufren un fuerte deterioro. Un agitador eólico fue probado para reproducir la mezcla del agua de la laguna en el interior de los corrales. Sin embargo, la penetración de la luz se redujo notablemente con este sistema. Los perfiles de temperatura dentro y fuera de los corrales mostraron que éstos estaban bien mezclados verticalmente, sin necesidad del sistema de agitación. Las diferencias en oxígeno disuelto entre la superficie y el fondo de los corrales, así como entre los corrales y la laguna fueron muy pequeñas.

Palabras clave: Mesocosmos, limnocorales, sedimentos, bentos, estuarios

INTRODUCTION

Much of the past research in aquatic ecology has been based on data collected in uncontrolled situ-

ations in the field. Indeed, the results of *in vitro* experiments cannot easily be extrapolated to complex natural ecosystems. On the other hand, the whole-lake experiments (Schindler, 1975)

include the risk of causing environmental damage (Berge *et al.*, 1986), and a large number of small samples is required to account for variability in natural systems.

To overcome this problem, researchers have used either artificial land-based models (Notini *et al.*, 1977) or enclosures that isolate a part of the aquatic ecosystem. Both systems are simplified models of the natural environment, expected to reasonably reproduce their main characteristics.

Different kinds of enclosures are defined according to their size. Mesocosms are 1 to 1000 m³ if they are pelagic or closed, or 0.1 to 100 m² if they are opened to the sediment. Microcosms and macrocosms are respectively smaller or bigger than those limits (UNESCO, 1991). Mesocosms are physically confined, self-sufficient systems including several trophic levels. Their volume must be large enough to avoid the wall effect (e.g., undesired growth of periphyton), and to allow frequent and relevant sampling. Enclosed populations maintain their natural proportions (Davies & Gamble, 1979), and when the mesocosms are installed, their ecological characteristics are identical to those of the natural system (Ravera, 1992). Although some alteration cannot be avoided, it can be minimized and checked by using a control (Lacaze, 1971).

Furthermore, mesocosms allow running experiments with many replicates. Although replicability is as important as the maintenance of natural conditions ("realism"), these properties seem to be inversely correlated (Kuiper *et al.*, 1983). According to Landner *et al.* (1989) realism must be favored against replication when the objective is to predict effects in natural systems, particularly secondary effects at the community or ecosystem level.

Mesocosms opened to the sediment play an important role in the study of pollution effects on pelagic-benthic interactions (Davies & Gamble, 1979; Ravera, 1992). This is particularly important concerning the effects of sewage on coastal areas where nutrients and pollutants rapidly reach the sediments.

Many different mesocosms have been developed, according to their objectives and type of water system (Davies & Gamble, 1979; Grice & Reeve, 1982; Ravera, 1989 and UNESCO, 1991). The first large mesocosm was the bag designed by Strickland & Terhune (1961) to measure primary production in the sea.

Tubes smaller than those proposed in 1956 by Margalef (McAllister *et al.*, 1961) did not maintain the natural populations due to the wall effect, which increases as the volume/surface ratio decreases (Lund, 1972).

The use of mesocosms increased in the 1970's. With the open tubes of Lund (1972) mesocosms were also used for freshwater environments, where they adopted the name of limnocorrals. Bodungen *et al.* (1976) included coastal sediments in the Plankton Tower of Kiel, whose exposure to the wind and marine surf required complex and heavy structures.

The use of mesocosms is more recent in coastal lagoons, where land-based tanks are generally used (Taylor *et al.*, 1995). In these tanks, water flows and mixing devices are needed. Furthermore, when sediment is introduced in the tank, the disturbance is generally high, unless extremely complicated systems are employed for their extraction and transport (Berge *et al.*, 1986).

Problems in the design of open mesocosms appear in areas affected by tides (Davies and Gamble, 1979) or by other important changes of water level. Coastal lagoons, like inter-tidal zones, are shallow, exposed to strong winds and currents, and experience continuously changing water levels. Although this variation does not exhibit the same frequency of tides, it is usually present in mid- and long-term experiments. Accordingly, mesocosms in both environments should allow a wide vertical displacement of water and resist adverse physical conditions. To overcome this problem, Schiewer (1997) designed mesocosms of polyethylene with a floating upper edge.

The presence of walls reduces the penetration of light, which in the confined environment of the mesocosm could result in an alteration of

the temperature regime. To prevent this, mesocosm walls consist of transparent plastic, except for mesocosms with a very large surface area. However, in shallow and usually turbid waters like those of coastal lagoons, confinement may actually lead to greater penetration of light resulting from reduced turbulence and sediment resuspension (Istvánovics *et al.*, 1986). This problem has been overcome in some cases with mixing devices.

Our purpose was to design a mesocosm to be used in experiments run in a coastal lagoon of the southern Atlantic Ocean. The main objective of this paper is to study the performance of the mesocosms developed as ecosystems and to

explore differences between the conditions inside and outside the mesocosm.

STUDY SITE

Laguna de Rocha (34° 37' S, 54° 12' W) has a surface area of 72 km² and a mean water depth of 0.6 m. It is located in Southeastern Uruguay (Fig. 1). Depth changes are frequent, due to the variation of flow in the main tributaries, which reach the lagoon from the north, and also to the periodic opening of the sandy bar that separates the lagoon from the southwest Atlantic Ocean. More details about this ecosystem can be found

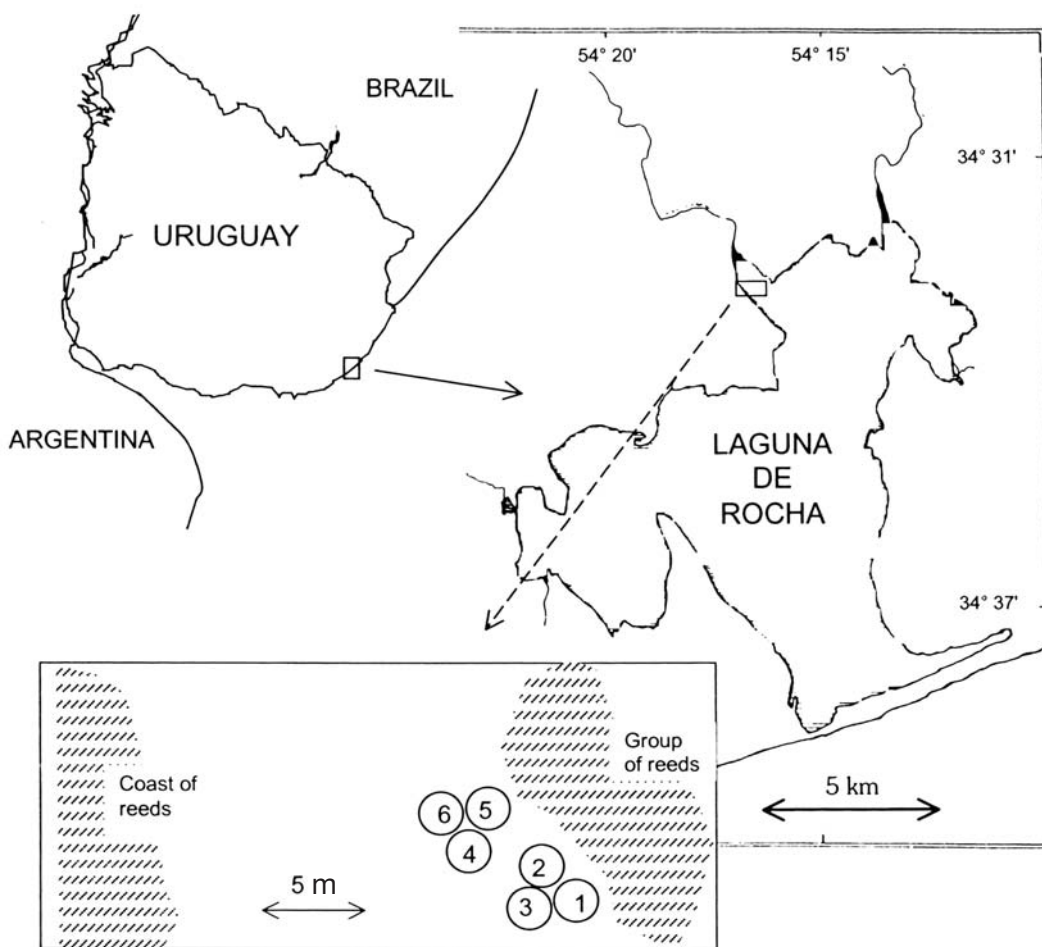


Figure 1. Location of Laguna de Rocha and the study area showing the location and numbering of the mesocosms. *Ubicación de la Laguna de Rocha y el área de estudio con la ubicación y numeración de los mesocosmos.*

in Sommaruga & Conde (1990), Pintos *et al.* (1991) and Conde *et al.* (1999).

MATERIAL AND METHODS

The area of the mesocosms was determined to be ten times larger than the area needed to collect monthly sediment samples of 10 replicates during one year with a corer of 6.0 cm in diameter (4 m²). The resulting diameter was 2.26 m and six mesocosms were installed in the lagoon on 16 and 17 September 1993.

The mesocosms had a rigid structure to avoid bending of the walls. Considering a mean depth of 0.6 m and foreseeing water level rises of up to 1 m, a height of 1.6 m was considered enough for water level fluctuations during the experiment. This supporting structure consisted in a grating (15 cm x 15 cm mesh), made 4.2 mm thick iron rods (Fig. 2). As the grating used was 2.5 m wide, it was cut and a third cylinder was made by welding the remaining thirds of every two gratings.

Six mesocosms were installed in a shallow site (35 cm) at the northern part of the lagoon (Fig. 1). The mesocosms were arranged in two groups of three units each like cloverleaves, and tied with wire. The gratings were buried between 20 cm and 32 cm in the sediment, thus the final height was between 135 and 147 cm. Furthermore, they were secured with four long rods completely buried in the sediment.

Four kinds of walls were successively tested within the gratings (Table 1): 1) common polyethylene (N), 2) thermic polyethylene (T), 3) two superimposed galvanized iron sheets (C), and 4) one single iron sheet (c).

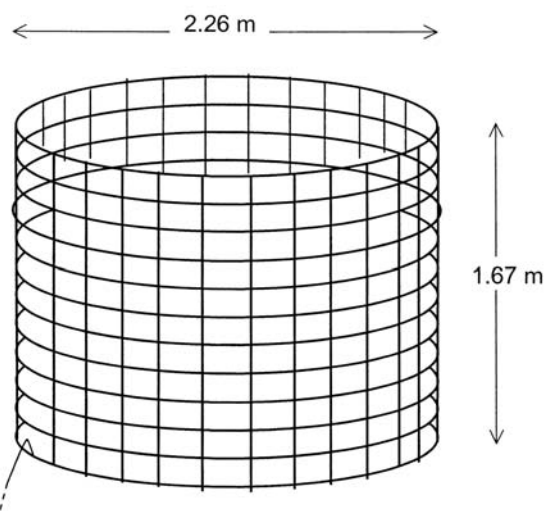


Figure 2. Supporting structure of iron grating. *Estructura de soporte de malla de hierro.*

Walls of common polyethylene

In a first design, rigid structures 1 and 2 were covered on both sides with a sheet of transparent polyethylene (N1, N2) 200 μm thick. The inner sheet was buried in the sediment by a galvanized iron cylinder 0.5 mm thick and 30 cm high. The polyethylene covered the inner side of the foil to prevent the pollution of the system with iron, and it was clinched to the sheet's lower edge folded outside (Fig. 3). The folding avoided the thin edge of the sheet cutting the polyethylene. The polyethylene sheet covered the upper edge and the external side of the grating. Hence, this external sheet protected the internal one that constituted the true wall of the mesocosm.

Table 1. Summary of the tested designs for mesocosms walls. *Resumen de los diseños utilizados para pared de los mesocosmos.*

WALLS MATERIAL	VARIABLES	ENCLOSURES	PERIOD
Common Polyethylene 200 μm	Light, Secchi disk	N1, N2 + mixer	17/Set/93 - 28/Set/93
Thermic Polyethylene 80-120 μm	Secchi disk Temperature	T5, T6	15/Dec/93 - 28/Jul/94
2 overlapped foils 0.8 mm	Dissolved Oxygen	C3	11/Jul/94 - 19/Jan/95
1 foil 1m x 0.8 mm	Conductivity	c1, c2	2/Dec/94 - 13/Jun/95

Walls of thermic polyethylene

In a variation of the first design, on December 15 1993, a low-density thermic polyethylene (80 - 120 μm thick) was installed in mesocosms 5 and 6 (T5, T6). This material is used for greenhouses, and it is less likely to suffer from damage than common polyethylene due to its higher elasticity.

Walls of two iron sheets

In July 1994, due to problems with polyethylene bags, an enclosure made of galvanized iron sheets 0.8 mm thick was tested in mesocosm 3 (C3). As this material is 1 m wide, two rings were clinched one above the other so as to reach enough height. Rings were painted with antioxidant and white enamel for marine use to increase its lifetime.

Walls of one iron sheet

Last, and because the water depth in December 1994 was only 60 cm, two enclosures made of only one 1 m high iron sheet were installed in gratings 1 and 2 (c1, c2). These were also painted and then covered with thermic polyethylene on both sides.

Device for water mixing

A wind-driven mixing system was incorporated into the mesocosm N2 to simulate the action of the wind in the lagoon. A very simple vertical axis whirl of Savonius type (Fig. 4) was made from a common metallic bucket. The 33 cm high rotor consisted of two semi-cylinders (29 cm diameter) with their concavities confronted but laterally displaced, and sustained between two disks (56 cm diameter). The whirl stood on an iron tripod attached to the upper edge of the grating. Its rotation was driven by the wind and transmitted by a 1.5 m long axis to a plastic helix from a domestic fan located 20 cm above the bottom. Friction pieces were made of hard polyethylene.

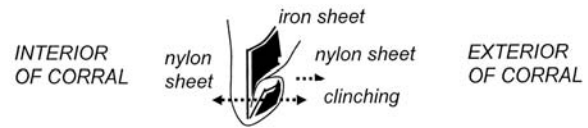


Figure 3. Detail of the joint between the lower edge of the polyethylene sheet and the metallic foil. *Detalle de la unión entre el borde inferior de la hoja de polietileno y la hoja metálica.*

Just after installation, the whirl speed was measured by direct counting its revolutions per minute (RPM). Simultaneously, the wind speed was measured with a mechanic anemometer to establish the relationship between both. This relationship allowed estimating the rotor speed from data on wind speed obtained from a meteorological station located 10 km from the experimental site.

Effects of the walls on environmental variables

To evaluate the change in the light conditions within the enclosures, Secchi disk (20 cm diameter) transparency was measured on 17 occasions from 17 September 1993, to 13 June 1995, inside and outside the mesocosms. The penetration of photosynthetically active radiation (PAR: 400-700 nm) was measured inside and outside with a radiometer (Li-Cor, LI-188B) connected to a 4π sensor. These measurements were carried out immediately after the enclosures were installed and 12 days after this.

Temperature and dissolved oxygen were measured several times with an YSI M57 oxymeter to evaluate the presence of vertical discontinuities in the polyethylene enclosures from September 1993 to February 1994, and those of galvanized iron from January to June 1995. The effect of the enclosure alone (N1) and that of the mixer (N2) on the temperature stratification were evaluated through four successive temperature profiles measured with an electronic thermocouple every 20 minutes on September 17, 1993 and every hour on September 28, 1993.

Percentages of light penetration were compared by a 3-way ANOVA without repetitions considering the interaction of site, date, and

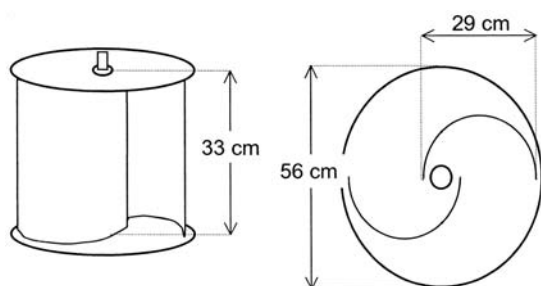


Figure 4. Wind driven Savonius rotor in frontal (left) and horizontal (right) view. *Rotor eólico tipo Savonius en vistas frontal (izquierda) y horizontal (derecha)*

depth as a measure of the error under the hypothesis that there was no effect added by such interaction (Sokal & Rohlf, 1979). Temperature and dissolved oxygen concentration data were analyzed in the same way. These analyses were carried out with the PC program STATISTICA (StatSoft, Inc.).

RESULTS

Functioning of the mesocosms

Supporting gratings remained in good condition for more than four years, including those constructed by two welded superimposed pieces. Their height, however, was insufficient, especially during an exceptional flood on April 7, 1995, when the water depth reached 2 m. This flood occurred a week after the highest daily rainfall (118 mm) registered during the study period. At that time the sandy bar of the lagoon was closed preventing its drainage into the sea.

The walls made of common polyethylene had to be repaired or replaced several times, and they

were finally discarded. Those walls made of thermic polyethylene stayed in acceptable condition during more than 7 months, with minimal maintenance. However, strong winds in the lagoon finally destroyed them too. The two sheets of the enclosure made of galvanized iron partially separated after 50 days. This was not a problem because the water depth never exceeded 70 cm during the whole period it was installed. Therefore, we opted to install two enclosures made of only one sheet. These enclosures lasted for more than 6 months, although the water covered them during the flood on April 7, 1995.

The mixer was removed on September 28, 1993 because it reached too high velocities (up to 74 RPM) and caused an excessive sediment resuspension. The speed of the rotor (R in RPM) was exponentially correlated to that of the wind (v in km h^{-1}) according to:

$$R = -4.518 + 4.498 e^{(0.099 v)}$$

$$(r = 0.999, p < 0.001).$$

The negative constant term indicates that the wind should reach a minimum velocity of 0.74 m min^{-1} to move the rotor. This relationship indicates that the rotor would reach 252 RPM with the highest wind velocity registered (40.7 km h^{-1}).

Effects of mesocosms on light penetration

In the first experiment using the radiometer, light penetration was the highest in the lagoon (L) and the lowest in the enclosure with the mixing system (N2), while values in the enclosure without mixing system (N1) laying in between

Table 2. Wind mean velocity (km h^{-1}) before sampling, according to the National Direction of Meteorology, and velocity of the rotor (RPM) as resulting from such data. *Velocidad media del viento (km h^{-1}) antes de cada muestreo, según la Dirección Nacional de Meteorología y velocidad del rotor (RPM) como resultado de esos datos.*

Date		8 a.m.	9 a.m.	10 a.m.	11 a.m.	12 p.m.	MEAN
17/Set/93	Wind			7.4	9.3	14.8	10.5
	Rotor			4.9	6.8	15.1	8.9
28/Set/93	Wind	11.1	20.4	16.7			16.1
	Rotor	9.1	29.6	19.1			19.3

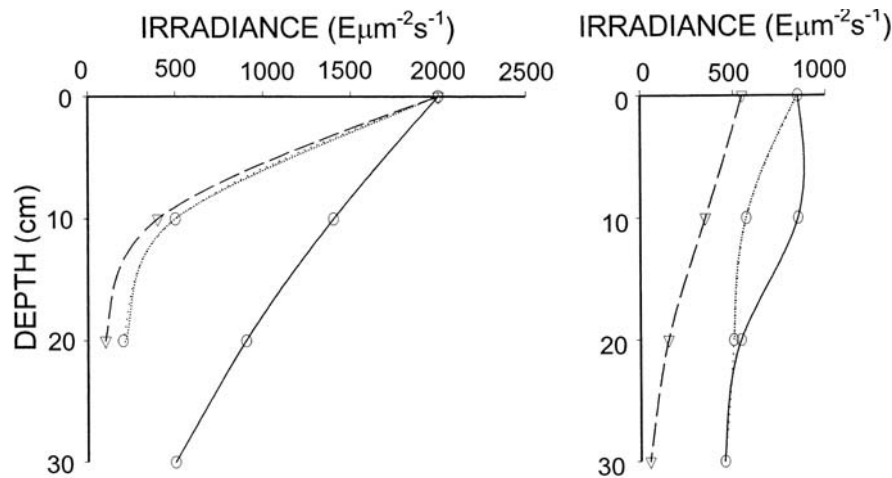


Figure 5. Light penetration outside (continuous line) and inside the enclosures N1 (dotted line) and N2 (dash line) measured one day after installation (September 17, 1993, left) and 12 days later (September 28, 1993, right). N2 was equipped with the mixer. *Penetración de la luz afuera (línea continua) y adentro del limnocorral N1 (línea punteada) y N2 (línea a rayas), medida un día después de la instalación (17 de setiembre de 1993, izquierda) y 12 días después (28 de setiembre de 1993, derecha). N2 estaba equipado con el agitador.*

(Fig. 5). On September 17, 1993 the PAR at 10 cm depth was reduced by 64% in N1 and by 71% in N2 when compared with the lagoon. Subsurface light intensity was equal at the three sites on the first date, but decreased on September 28, 1993 in N2. The wind velocity was higher on this second date (Table 2), generating more than two-fold higher rotor speeds.

The ANOVA on the percentages of light penetration indicated differences for the three fac-

tors considered, i.e. date, depth, and site, but not for their interactions (Table 3). Light penetration was different between L and N2 (Table 4), but not between each of them and N1. However, when comparing each site with the other two combined, only L was significantly different from both enclosures, although the probability of N2 to be equal to L + N1 was low.

On the other hand, in the other experiments Secchi disk transparency always reached the

Table 3. F values for 3 way ANOVA of: 1) light percentage in the lagoon and in enclosures N1 and N2 (with rotor), 2) temperature and dissolved oxygen measured on 4 and 5 dates, respectively, in the lagoon and in a polyethylene enclosure, and 3) on 7 dates in the lagoon and in two iron ring enclosures (*p<0.05, **p<0.01). *Valores de F del ANOVA de 3 vías para 1) porcentaje de luz en la laguna y limnocorrales N1 y N2 (con rotor), 2) temperatura y oxígeno disuelto medido en 4 y 5 fechas, respectivamente, en la laguna y en el limnocorral de polietileno, y 3) en 7 fechas en la laguna y en dos limnocorrales de chapa (*p<0.05, **p<0.01).*

Source of variation	Polyethylene Enclosures (N)			Iron Foil Enclosure (c)	
	Light	Temperature	Oxygen	Temperature	Oxygen
Principal					
Site	29.990**	2.025	243.0*	2.005	3.511
Depth	23.267**	1.225	27.00*	7.775*	9.735*
Day	63.273**	478.6*	38705*	611.8*	169.8*
Interactions					
Day-Depth	0.465	0.8500	5.000	1.011	9.174*
Day-Site	3.797	0.4000	133.0*	2.771*	2.476
Depth-Site	1.145	0.6250	3.000	1.019	0.7708

bottom at both, the mesocosms and the lagoon (30 - 145 cm, average 60 cm), except during the exceptional flood on April 7, 1995, when it was only 45 cm in all the environments.

Effects on stratification and heat transmission

In the first experiment, thermal profiles done on September 17, 1993, showed that a vertical difference of 1.2 °C in enclosure N1 was reduced to only 0.1 °C in less than one hour (Fig. 6). At the beginning, the temperature in the lagoon was 1 °C higher than at the bottom of N1, but at the end it was 0.7 °C higher in the latter than in the lagoon. The temperature was different among times (ANOVA, $p < 0.02$). It increased inside the enclosures, while it remained almost constant outside. This suggests that a slight increase in water temperature occurs in the enclosures at noon.

In later comparisons of temperature made from September 1993 to February 1994 with

the polyethylene enclosure (14.3-23.0 °C), neither vertical nor among-sites differences were found (Table 3). The enclosures of galvanized iron did not show among-sites differences either. Furthermore, they had no effect on the differences found between surface and bottom, as shown by the lack of site-depth interaction. The greatest temperature difference in the water column (22.5 - 20.5 °C) occurred during the flood on April 7, 1995 in c1. An ANOVA eliminating that date was also significant, hence the difference could be due to all values being slightly higher at the surface. The significant interaction between sites and days points out to the effect of the iron enclosures on the temporal variation of temperature.

Oxygen was significantly higher at the surface (7.2 - 13.4 mg L⁻¹) than at the bottom (7.1 - 13.4 mg L⁻¹) of the polyethylene enclosure, but the greatest difference was only 0.2 mg L⁻¹. Such differences were not caused by the enclosure, as shown by the lack of site-depth interactions (Table 3). Although the oxygen was significantly lower in the polyethylene enclosures (7.1 - 13.4 mg L⁻¹) than in the lagoon (7.6 - 13.8 mg L⁻¹), the difference was always less than 0.6 mg L⁻¹. The enclosure with the mixer showed 2.8 mg L⁻¹ less dissolved oxygen than the lagoon and up to 2.4 mg L⁻¹ less than the enclosure without mixer.

In the latter experiences with iron enclosures no differences with the lagoon were found in the oxygen concentrations, although the surface was more oxygenated than the bottom (Table 5). The highest differences occurred during the flood on April 7, 1995. When the test was done eliminating this date, the vertical differences were no

Table 4. P values for comparisons of light percentage at 10 and 20 cm depth on September 17 and 28, 1993, between the lagoon (L) and enclosures N1 and N2, and between each site and the other two together. *Valores de probabilidad (p) para las comparaciones entre los porcentajes de luz a 10 y 20 cm de profundidad, el 17 y 28 de setiembre de 1993, entre la laguna (L) y los limnocorrales N1 y N2, y entre cada sitio y los otros dos juntos.*

SITE	L	N1	N2
L		0.1147	0.0189
N1			0.3545
N1+N2	0.0252		
L+N2		0.6838	
L+N1			0.0561

Table 5. Surface (s) and bottom (b) dissolved oxygen (mg L⁻¹) in the lagoon (L) and in the two iron sheet enclosures (c1 and c2). *Oxígeno disuelto (mg L⁻¹) en la superficie (s) y fondo (b) de la laguna (L) y en dos limnocorrales de chapa (c1 y c2).*

DATE	Ls	Lb	c1s	c1b	c2s	c2b
19/Jan/95	13.0	13.1	12.8	14.0	13.2	14.2
15/Feb	6.0	6.0	6.0	5.6	7.4	7.4
18/Mar	6.6	6.0	8.8	8.0	7.1	6.9
7/Apr	5.8	0.3	5.8	3.0	5.8	3.4
4/May	8.9	8.0	7.9	7.9	8.7	8.5
13/Jun	10.0	11.0	10.3	10.0	10.2	9.6

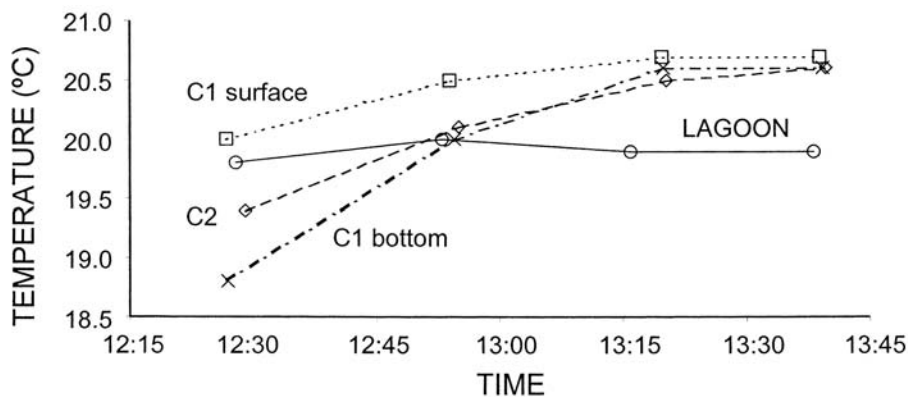


Figure 6. Water temperature in the lagoon and in enclosures N1 and N2, on September 17, 1993. In N1 different values for surface and bottom were registered. *Temperatura del agua en la laguna y en los limnocorales N1 y N2, el 17 de septiembre de 1993. En N1 se registraron diferentes valores para superficie y fondo.*

longer significant. The interaction between sites and days highlights the effect of the polyethylene enclosures on the temporal variation of dissolved oxygen concentrations. The same results were obtained when the analyses were repeated using the percentage of oxygen saturation instead of absolute concentrations.

DISCUSSION

During this work, we tested different materials for open mesocosms suitable for coastal lagoons, which experience strong winds and variable water levels. For mesocosms of dimensions similar to those used in this study floating edges are not appropriate. Nevertheless, these could be useful for bigger enclosures where the folding of the walls resulting from decreasing water levels would cover only a small part of the enclosed sediment.

The iron gratings employed as supporting structures are highly resistant. They can be deeply buried, tied to one another, and secured by rods introduced in the sediment. Their transport is relatively simple because they can be rolled, and then placed to form a cylinder. The durability of the gratings and the possibility of replacing the walls make them suitable for reuse after allowing adequate time for the sediments to recover their natural characteristics.

The enclosures can be built of the diameter desired for the research objectives, as the grating is sold at the required length. The height can be extended by welding two pieces as demonstrated by the structures compounded in this manner. Unfortunately, there are no official records for the depth variation in Laguna de Rocha, and we could not foresee the unusually high flood of April 7, 1995.

The low-density thermic polyethylene proved to be much more resistant than the common polyethylene, in spite of their lower thickness. However, these materials must also be replaced after few months of exposure to the strong winds in coastal lagoons. The only material able to resist these adverse meteorological conditions seems to be galvanized iron sheets. One ring is the most suitable design whenever the water is shallow enough. The pollution with iron can be mitigated and the oxidation made slower when the iron sheets are properly painted and covered with thermic polyethylene on both sides.

In other designs, with rigid walls that prevent sediment resuspension, it is possible to install a system of water mixing similar to the one tested here. The Savonius rotor is a good option for its simplicity, and because it whirls at a speed proportional to the wind. In our case the system turned out to be not only unnecessary, but also inappropriate because it developed an excessive velocity. This problem, how-

ever, can be addressed by reducing the size of the rotor, increasing the overlapping of wings or perforating them.

The mixer decreases light penetration through the resuspension of sediment. If not removed, it could strongly limit benthic production, as observed in the inter-tidal mesocosms by Farke *et al.* (1984), where it was reduced by 30%. This production is of special importance in shallow systems: in the northern zone of Laguna de Rocha it reached $20.6 \text{ mg C m}^{-2} \text{ h}^{-1}$ in August 1997, while the average for that year represented approximately 30% of the phytoplankton production (D. Conde, pers. comm.).

Apart from reducing the light penetration, the mixer caused a decrease in oxygen through the resuspension of sediment. Furthermore, the mechanical mixing of water proved to be unnecessary when the mesocosms' walls were flexible enough to transmit the movement of waves to the interior of the enclosures. This was not the case with the polyethylene as well as with the iron walls.

Light penetration was lower than in the mesocosms of Strickland & Terhune (1961) but higher than in those of Bodungen *et al.* (1976), which lifted the euphotic zone to half of its natural depth. In our study, the euphotic zone extends to the bottom even inside the enclosures. On the other hand, according to Bodungen *et al.* (1976) some reduction of the light field would be beneficial as it limits the development of periphyton inside the mesocosms.

The polyethylene cylinders of Goldman (1962) reduced the Secchi disk transparency by 1 m. Conversely, this increased 20 cm in the opened limnocorrals of Balaton Lake, due to the confinement of its usually turbid water (Istvánovics *et al.*, 1986). In our case, the Secchi disk transparency was always the same outside and inside the enclosures in all the experiments.

An increase in temperature inside the enclosures is inevitable (Farke *et al.* 1984). The cylinders of Goldman (1962) produced a slight warming of the water, and hence increased the resistance to mixing within a few days.

Steele *et al.* (1977) found that the external fluctuations of temperature were strongly reduced inside their plastic bags. Temperature in the spheres of Strickland followed the external one with a one-day lag (McAllister *et al.*, 1961). Increases in water temperature in our enclosures, observed only during the short-term measurements, may prevent them from being used for brief and temperature-dependent experiments such as primary production measurements. The slight temperature increase in the enclosures can be explained by the confinement of the water. They receive high levels of thermal radiation at noon without the possibility of heat dissipation as it happens in the lagoon. In addition, the radiation could be enhanced by its reflection on the walls, which become opaque and whitish after a while.

The polyethylene enclosures showed some oxygen differences, both vertically and compared to the lagoon. They also affected temporal changes of dissolved oxygen. These differences, however, were small and did not alter oxygenation in the enclosures.

The iron enclosures resembled better the external environment but they caused more vertical differences in physical parameters as a consequence of their more rigid walls that reduced the movement of water. At the same time, they affected the temporal variation of temperature, probably by limiting the thermal conduction through the metal. However, the vertical differences of temperature and dissolved oxygen were not great.

During the flood on April 7, 1995 anoxia was noticed at the bottom of the lagoon and hypoxia at the bottom of the enclosure, i.e. a good reproduction of the extreme situation in the natural environment. Floods carry a high load of suspended solids, which may decrease the light and exhaust the oxygen in the lagoon, but the confined environment of the enclosure was not so deeply influenced, maintaining more dissolved oxygen at the bottom.

The values of the physical and chemical water parameters in the different mesocosms confirm that these systems are suitable for mid-term studies of several weeks to several months.

Very short-term experiments may be influenced by the confinement of the water. The damage to the enclosures, in these environments dominated by strong physical forces, make them unsuitable for long-term experiments unless maintained and repaired every 5-6 months.

In summary, the supporting structure has proved to be very useful as support for benthic mesocosm in coastal lagoons. For short term experiments (weeks, e.g. plankton) polyethylene walls may be adequate but are unsuitable for longer experiments. Iron walls have proved to be very resistant (up to several months) in this environment and are adequate for longer experiments (e.g. benthos).

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