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Extensive cage culture of pejerrey (*Odontesthes bonariensis*) in a shallow pampean lake in Argentina

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Abstract

Pejerrey is an important zooplanktivorous native fish of the Argentinean inland waters. It has been traditionally propagated for stocking purposes by relatively costly semi-intensive and intensive methods. In this study, we evaluated the implementation of an extensive culture method by using floating cages in a shallow pampean lake. Four cages were installed in the Lacombe Lake and stocked with juveniles (16.24 ± 1.69 mm length) at 50 fish m^{-3} density for growing until the size of 150 mm, which is considered as a suitable size for stocking. Throughout the experiment, the temperature ranged between 10 and 26 °C and the zooplankton biomass ranged between 12 and 3269 $\mu g\, dw\, L^{-1}$. The growth patterns in the length were similar in the four cages and directly related to the lake thermal conditions and zooplankton availability. The average final length after 315 days was 154.4 ± 8.8 mm. The survival rates ranged between 53.5% and 64.7% during the first 110 days and 11.1–25.7% at termination. Growth rate for the first 2 months was the highest documented for pejerrey culture. This simple technique offers the possibility to produce juvenile pejerrey at a low cost and provides the alternative of reinforcing the natural populations with fish already adapted to the natural environmental conditions.

Keywords: *Odontesthes bonariensis*, cage culture, pampean lakes, fish growth, zooplanktivorous fish

Introduction

The pejerrey (*Odontesthes bonariensis)* is considered as one of the most important commercial and sport fish species inhabiting the inland waters of Argentina (Bonetto & Castello 1985; Grosman 1995; Reartes 1995; Somoza, Miranda, Berasain, Colautti, Remes Lenicov & Strüssmann 2008). Because of the high quality of its flesh and sport fishing attractiveness, it has been introduced with a relatively good success to other South American, European and Asian countries (Loubens & Osorio 1992; Toda, Tonami, Yasuda & Suzuki 1995; Strüssmann & Yasuda 2005). The interest in this species stimulated the first culture attempts for stocking at the beginning of the past century. Since then, the techniques of pejerrey production have improved progressively and it is possible at present to complete the production cycle in tanks (Miranda, Berasain, Velasco, Shirojo & Somoza 2006). Although pejerrey culture has a long history of development in Argentina, most programmes are focused on larval hatching and fingerling stocking for population enhancement, due to the lack of the necessary infrastructure and the high costs for producing juveniles. In any case, the importance of pejerrey in Argentina is reflected in the fact that >10 million larvae are released into pampean lakes each year (Buenos Aires Agrarian Ministry 2009).

The pejerrey is mainly a zooplanktivorous fish that feeds mostly on algae and rotifers during its post-larval stage and cladocerans and copepods during the juvenile and adult stages (Destefanis & Freyre 1972; Ringuelet, Iriart & Escalante 1980). Because pampean lakes are usually eutrophic, zooplankton represents an important and abundant community (Escalante 2001; Claps, Gabellone & Benítez 2004). This feature represents a unique opportunity for developing pejerrey culture based on natural zooplankton as the source of food. The use of cages is a well-developed technology that has been mostly used for semi-extensive and intensive fish culture (Masser & Bridger 2007), including the culture of salmonids and tilapia in South America (Rojas & Wadsworth 2007). Because of its practicability, cage culture has been envisioned as an alternative to traditional rearing techniques (Beveridge 2004). This technique has been successfully implemented for many species such as *Oreochromis niloticus* (Cavailles, Konan & Doudet 1981), *Sarotherodon melanotheron* (Ouattara, Teugels, N'Douba & Philippart 2003), *Heterobranchus longifilis* (Coulibaly, Ouattara, Koné, N'Douba, Snoeks, Gooré Bi & Kouamélan 2006), *Rhamdia quelen* (Barcellos, Kreutz, Quevedo, Fioreze, Cericato, Soso, Fagundes, Conrad, Krammer Baldfisera, Bruschi & Ritter 2004), *Colossoma macropomum* (Merola & De Souza 1988; Chellapa, Chellapa, Barbosa, Huntingford & Beveridge 1995) and *Clarias gariepinus* (Hengsawat, Ward & Jaruratjamorn 1997), among others. Cage culture without supplying artificial food is a less common practice, but illuminated cages have been used to raise early stages of zooplanktivorous species (Dostatni, Mamcarz, Koztowski & Poczyczyñski 1999) even in mesotrophic lakes (Žiliukienè 2005). Phytoplanktivorous fish have also been produced by extensive cage culture (Bocci 1999; Rai 1999). In the case of the pejerrey, little is known about the feasibility of cultivation using natural zooplankton. Preliminary results obtained by Colautti and Remes Lenicov (2001) showed that small pejerrey juveniles reared in cages exhibited better conditions and higher growth rates than those cultured in ponds.

We present here the results of the survival and growth of *O. bonariensis* cultured in floating cages during the juvenile stage, as a first step to evaluate the feasibility of this extensive culture practice. We also explored how factors such as temperature and zooplankton availability could influence cage culture feasibility in shallow pampean lakes from Argentina.

Materials and methods

Experiments were conducted in the Lacombe Lake (35.833°S, 57.887°W), an eutrophic shallow water body located in the pampean region, Argentina (Fig. 1), where four floating cages were operated from January 2006 to November 2006. Each cage was 3.45 m in length, 3.45 m in width and 1.4 m in depth (1 m effectively submerged) with a frame (4.1 × 4.1 m) constructed from wood and empty plastic drums. The cage nets were of monofilament nylon, and during the first 110 days of the experiment a 2 × 2-mm-mesh size was used. After that, the mesh was changed for a 4 × 8-mm-mesh size in order to increase water exchange between the cage and the lake and to avoid mesh obstruction by fouling.

A total of 600 15-day-old juveniles, hatched and reared in nursery cages at the Technological Institute of Chascomús (INTECH), were stocked in each cage at 50 fish m^{-3}. Initial total length and weight were 16.24 ± 1.69 mm and 0.019 ± 0.006 g respectively.

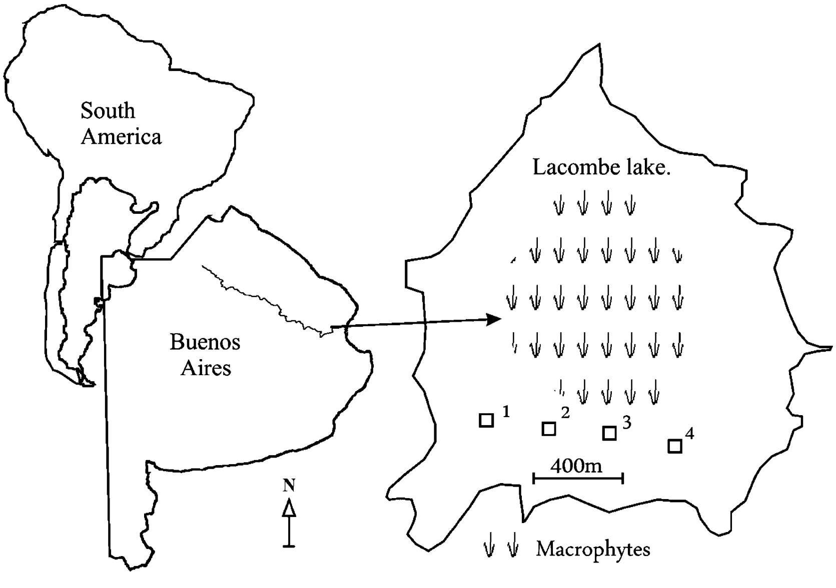

Figure 1 Geographical position of Lacombe Lake and location of cages used in this study.

Measurements of limnological parameters and zooplankton as well as fish samples were obtained approximately every 15 days during the first 60 days and at intervals of 30 days thereafter. Conductivity, pH and turbidity were measured using a multi parameter sensor (Horiba U10, Kyoto, Japan); dissolved oxygen was obtained using an oxygen meter (Lutron DO-5508, Taipei, Taiwan). Temperature was recorded using a thermologger (Thermochron iButton, Sunnyvale, CA, USA) throughout the experiment at 1 h intervals. Zooplankton samples were taken inside and outside the cages at each sampling date by filtering 20 litres of water through a 70-μm-mesh size plankton net, after which the samples were preserved with formaldehyde (5%). Sedgwick–Rafter (APHA 1995) and Bogorov (Gannon 1971) counting chambers were used for the quali–quantitative analysis of the zooplankton samples. Adult forms were identified as Cladocera, Calanoida or Cyclopoida and young forms as nauplii or copepodites. Zooplankton was counted to obtain their mean densities per litre [individuals (ind.) L^{-1}] and subsamples of each group were measured to obtain an estimate of their size (length) distribution. Dry weight biomass per litre (μg dw L^{-1}) for every zooplankton group and for the total amount of zooplankton were calculated using the weight–length relationships as suggested by Bottrell, Duncan, Gliwicz, Grygierek, Herzig, Hillbricht-Ilkowska, Kurasawa, Larsson and Weglenska (1976) and Dumont, Van de Velde and Dumont (1975).

At each sampling date, 10 fish were randomly collected, measured (total length) and weighed (total weight) with 1 mm and 0.001 g precision respectively. At 110 and 315 days of rearing, all fish were counted for survival rate estimation. Comparisons of this parameter between cages, at each date, were made using the χ^2-test for equality of distribution. Mean daily length gain (M_{dlg}) and mean daily weight gain (M_{dwg}) for both sampling intervals and the entire period, mean final weight (M_{fw}) and production per area (P) were calculated as follows:

$$M_{\mathrm{dlg}}\,(\mathrm{mm\,day^{-1}}) = (\mathrm{TL}_2 - \mathrm{TL}_1)/(\mathrm{t}_2 - \mathrm{t}_1)$$

where TL_2 and TL_1 are mean total lengths at time 2 (t_2) and at time 1 (t_1) respectively.

$$M_{\mathrm{dwg}}\,(\mathrm{g\,day^{-1}}) = (\mathrm{W}_2 - \mathrm{W}_1)/(\mathrm{t}_2 - \mathrm{t}_1)$$

where W is the mean weight.

$$M_{\mathrm{fw}}\ (\mathrm{g}) = T_{\mathrm{w}}/N_{\mathrm{f}}$$

where T_{w} is the total weight and N_{f} the final number of fish.

$$P\ (\mathrm{kg\ ha^{-1}}) = (T_{\mathrm{w}} \times 10\,000)/S$$

where S is the cage area in m^2.

Differences in zooplankton biomass and fish length between the cages at each sampling date were tested with ANOVA followed by the Tukey test when significant differences were observed (Zar 1984). The M_{dlg} and M_{dwg} at each sampling interval were correlated with the respective mean temperatures and zooplankton biomass using the Pearson coefficient. The same coefficient was used to analyse the relationship between survival and growth rate in order to evaluate density-dependent effects on growth.

(Correction added on 26 July 2010, after first online publication: In the formula above, M_{fw} was corrected to T_{w}.)

Results

Limnological and physical–chemical characteristics of Lacombe Lake

Lacombe Lake exhibited limnological characteristics similar to those of other shallow pampean lakes. The water body area and maximum depth were 130 ha and 2.5 m respectively. The physical–chemical characteristics were on average alkaline (pH = 9.89), with moderate conductivity (2560 μS cm^{-1}), turbidity (48 NTU) and suitable dissolved oxygen (9 mg L^{-1}). The temperature ranged between 28 °C in February and 7 °C in August, showing a typical seasonal fluctuation (Fig. 2a).

Zooplankton abundance and composition

Zooplankton densities varied seasonally between 30 and 2605 ind. L^{-1} in lake samples and between 55 and 2448 ind. L^{-1} in the cages (Table 1). In both cases, the minimum value was recorded in January and the maximum in October. The microcrustacean assemblage was dominated by nauplii larvae (406 ind. L^{-1} on average) during most of the experiment. A peak of adult cladocerans and copepods was observed in September. In lake samples, cladocerans predominated in summer and spring (70 ind. L^{-1} in February and 1300 ind. L^{-1} in September) and calanoid copepods in autumn and winter (50 ind. L^{-1} in April and June). In cage samples, cladocerans also dominated in summer and spring (231 ind. L^{-1} in February and 1137 ind. L^{-1} in September) but no group was dominant in density in the middle of the experiment. In terms of relative composition of lake zooplankton biomass, calanoid

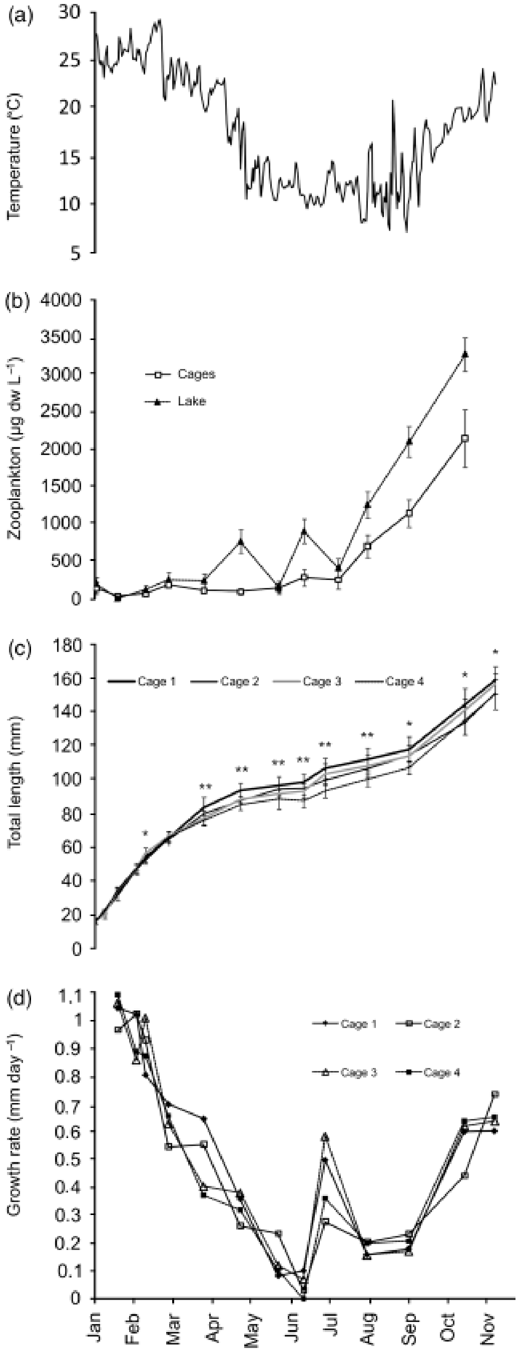

Figure 2 (a) Average daily water temperatures in Lacombe Lake during the study period; (b) Average ± SD zooplankton biomass (dry weight $\mu g\,L^{-1}$) of samples taken from lake and cages respectively, along the study period; (c) Mean total length ± SD of pejerrey fingerlings grown in the four floating cages (ANOVA differences; $^{*}P<0.05$, $^{**}P<0.01$); (d) Mean daily length gain ($mm\,day^{-1}$) during the rearing period.

Table 1 Total zooplankton abundance [individuals (ind.) L^{-1}] at each sampling date in lake and cages

Date	Lake (ind. L^{-1})	Cages (ind. L^{-1})
January (a)	422	372
January (b)	30	55
February (a)	365	215
February (b)	613	730
March	390	414
April	664	358
May	252	305
June	957	628
July	389	317
August	980	912
September	1572	1507
October	2605	2448

copepods showed the highest biomass during autumn ($445\,\mu g\,dw\,L^{-1}$ in April and $409\,\mu g\,dw\,L^{-1}$ in June), cladocerans (mainly *Bosmina huaronensis*) in August ($815\,\mu g\,dw\,L^{-1}$) and September ($1589\,\mu g\,dw\,L^{-1}$) and cyclopoid copepods in October ($958\,\mu g\,dw\,L^{-1}$) (Figs 2b and 3).

The zooplankton biomass from both the lake and cages followed similar trends except during 2 months in autumn and winter, indicating that the cage mesh size did not represent a selective barrier for zooplankton exchange (Fig. 2b). The peak of total zooplankton biomass was observed in October ($3269\,\mu g\,dw\,L^{-1}$). No significant differences were found in zooplankton biomass among cages but lake zooplankton biomass was significantly higher than those found in cages (ANOVA $F = 9.03$; $P<0.01$). This difference was more evident during the last three months, suggesting a possible regulation of zooplankton abundance in the cages by the growing fish (Fig. 2b).

Growth and survival of the fish

Significant differences in mean length of pejerrey were observed after 4 months and cages 1 and 4 generally had the highest and lowest means respectively (Fig. 2c). All cages followed a similar trend of larger total length increments in spring and summer and smaller increments in autumn and winter. Growth rates followed temperature patterns in all cages (Fig. 2a, d) with a significant relationship between both variables (average $r = 0.80$; $P<0.05$). An exception to this pattern was observed in winter when there was a substantial increase in growth rates. The most noticeable increase in growth rates,

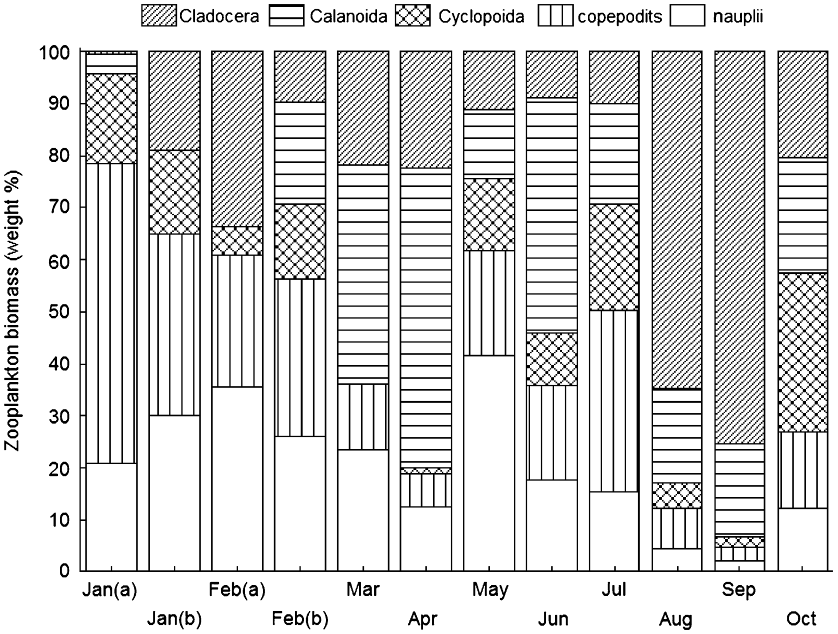

Figure 3 Relative composition of zooplankton biomass (weight %) at each sampling date.

which also corresponded to the greatest fish biomass accumulation, was observed during the spring months, in association with increasing zooplankton biomass (over 1000 μg dw L^{-1}) (Fig. 2b, d). Growth rates were correlated to zooplankton biomass availability in all cages ($r = 0.68$; $P < 0.05$). Mean final weight and length differed significantly between cages ($F = 3.62$, $P < 0.05$ and $F = 3.13$, $P < 0.05$ respectively) (Table 2). These two parameters, as well as the mean daily weight and length gains were significantly higher in cage 1 than in cage 4.

Survival rates ranged between 54% and 65% for the first 110 days, with significant differences between most cages (Table 2). Survival rates at the end of the experimental period ranged between 11% and 25% and were significantly lower in cages 2 and 3 than in cages 1 and 4. No significant correlation was found between survival and growth rate ($r = -0.18$, $P = 0.81$). Final biomass and estimated production per area also showed differences between cages ranging between approximately 1200 and 3300 kg ha^{-1} (Table 2).

Discussion

Past pejerrey management strategies in pampean lakes consisted in stocking hatched larvae of only 6–7 mm, despite their natural high mortality (Iwaszkiw & Freyre 1980; Luchini, Quirós & Avedaño 1984; Berasain, Velasco & Colautti 2001). Survival rate is a critical parameter influencing the cost–benefit of extensive cage culture or any other method of seed production. Short-term rearing studies with small juveniles that were performed in semi-intensive ponds yielded survival rates of 26% in 161 days and 18% in 233 days (Luchini *et al.* 1984), whereas under intensive culture conditions the survival rates were 71.6% and 79.6% in 30 days (Berasain, Colautti & Velasco 2000), 40% and 73% in 89 days (Berasain, Velasco, Shiroyo, Colautti & Remes Lenicov 2006), 60.76% in 64 days (Miranda *et al.* 2006) and 57% in 196 days (Velasco, Berasain & Ohashi 2008). Colautti and Remes Lenicov (2001) obtained a survival of 18% up to 150 days when rearing pejerrey in Lake Navarro but only 10% at 209 days. The authors attributed these low values to vandalism and technical failures. In the Lacombe Lake, survival ranged between 53% and 65% for the first 110 days and 11–25% for 315 days. Thus, the survival rates obtained, particularly for the first 110 cage culture days, can be considered satisfactory as compared with previous studies. The growth performance obtained for the entire study cannot be properly compared with those of previous studies because most of them comprised of only a short period (around 45–60 days) of post-larval rearing (5–10 mm). However, considering only the first 57 days of the experiment, when we obtained a daily

Table 2 Growth performance of pejerrey cultured for 315 days in floating cages at Lake Lacombe

	Cage			
Performance measurements	**1**	**2**	**3**	**4**
Final total weight (g cage^{-1})	4024.03	1471.58	1701.21	2729.89
Mean final weight (g fish^{-1})	25.47 ± 3.93^{a}	21.64 ± 4.89^{ab}	24.30 ± 2.53^{ab}	20.99 ± 3.94^{b}
Mean final total length (mm fish^{-1})	158.86 ± 8.15^{a}	151 ± 9.39^{ab}	156.5 ± 6.13^{ab}	150.33 ± 8.77^{b}
Mean daily weight gain (g day^{-1})	0.081	0.069	0.077	0.067
Mean daily length gain (mm day^{-1})	0.453	0.428	0.445	0.426
Survival at 110 days (%)	57.10^{ab}	53.51^{a}	60.24^{b}	64.65^{c}
Survival at 315 days (%)	25.77^{a}	11.09^{b}	11.43^{b}	21.22^{a}
Production (kg ha^{-1})	3381	1236	1429	2294

Values of measurements are means accompanied by their respective standard deviations. Significant differences ($P < 0.05$) among cages are indicated in superscript letters.

growth rate with a length of 0.86 mm day^{-1}, it becomes evident that the performance in our study is one of the highest reported so far for juvenile pejerrey culture (Table 3). This suggests that extensive cage culture in pampean lakes is a low-cost alternative for producing 2-month-old juveniles at moderate densities.

Table 3 Comparison of the mean daily length growth of pejerrey reared under intensive, semi-intensive, and extensive culture conditions during the first 45–60 days of life

Culture type	**Mean daily length growth (mm day^{-1})**	**Temperature range (min–max, °C)**	**Reference**
Semi intensive in tanks	0.51	17.5–23.0	Grosman and González Castelain (1996)
Intensive in tanks	0.60	23.4 (mean)	Berasain *et al.* (2000)
Extensive in cages	0.49	Not available	Colautti and Remes Lenicov (2001)
Intensive in tanks	0.53	18.5–23.7	Miranda *et al.* (2006)
Intensive in tanks	0.67	22.3–25.6	Velasco *et al.* (2008)
Extensive in cages	0.86	20.8–29.2	This study

min, minimum; max, maximum.

It is important to point out that pejerrey growth in pampean lakes appears to be strongly related to thermal patterns as well as food quality and availability. The dependency of pejerrey on zooplankton has been shown already in wild populations, whereby body condition was closely related to zooplankton abundance (Colautti, Remes Lenicov & Berasain 2003). Moreover, Velasco *et al.* (2008) fed larvae with zooplankton in tanks and observed that maximum growth rates were achieved during the summer months and that food intake decreased at temperatures below 15 °C. Our results followed a similar trend and highest growth rates were associated with warmer temperatures in spring and summer and with the seasonal abundance of the major groups of zooplankton in the Lacombe Lake, e.g. copepods and cladocerans. These results are consistent with the notion that temperature has not only a critical seasonal influence on metabolic demands, regulating the input energy derived to fish growth but also has a major influence on ecosystem functioning processes (Wootton 1990). An exception to this pattern was observed during the colder months, when growth was temporarily enhanced due to peaks in the biomass of calanoid copepods, which apparently provided a high-quality food supply for pejerrey. Thus, increases in either zooplankton or temperature were followed by noticeable increases in pejerrey growth rates.

It is also interesting to note that cages 1 and 4 contained fish with the highest and lowest values of mean daily weight and length gain and mean final length and weight respectively. On the other hand, both cages had the highest final survival rates, suggesting that fish density used in this study had little or no effect on the results of growth. In the case of zooplanktivorous fish, it is necessary to assess how hydrodynamic conditions and lake morphology might affect zooplankton distribution. For example, in another pampean lake, the Lake Monte, Claps *et al.* (2004) found that zooplankton distribution differed within the lake. Thus, we expected some degree of variation in the abundance of zooplankton between cages. However, zooplankton density did not differ significantly among cages, implying that the observed variability in production was probably caused by other factors. In other words, the observed differences may be accounted for by density-independent factors such as cage location within the lake, water circulation and temporary depletion of dissolved oxygen, among others (Huguenin 1997; Beveridge 2004). Coche (1978) warned that cage location within the water body can play an important role in keeping production high. We hypothesize that in the Lacombe Lake, cages 1 and 4 produced the maximum biomass and exhibited the highest survival rates because they were settled in shallower areas lacking surrounding macrophytes. This location could have enhanced cage water exchange due to wind effects.

Based on the results of this study, we suggest that a zooplankton biomass of at least 1000 μg dw L^{-1} during the warmer months and consisting predominantly of macrozooplankton such as copepods and cladocerans, is a key element supporting the growth of pejerrey juveniles in natural stocks. The zooplankton composition of Lacombe Lake appears to be similar to that described for other pampean lakes (Boltovskoy, Dippolito, Foggetta, Gómez & Alvarez 1990; Benítez & Claps 2000; Gabellone, Solari & Claps 2001). Likewise, although there is not much information about zooplankton biomass in pampean shallow lakes, the biomass found in this study (maximum biomass in the lake: 3269 μg dw L^{-1}) is comparable with that from other eutrophic shallow environments of Argentina (maximum biomass: 3987 μg dw L^{-1}) (Claps *et al.* 2004). Thus, the Lacombe Lake is a typical water body of this region. If the findings for this lake can be extrapolated to other pampean lakes with a similar natural productivity, this would indicate that other water bodies in the region also offer appropriate conditions for developing extensive pejerrey culture in cages. However, more efforts should be devoted to assessing how environmental parameters such as temperature and food availability could affect pejerrey survival. In addition, lakes showing less hydrological variability and lower turnover rates should be more suitable for extensive pejerrey culture due to minimization of zooplankton dilution or drift.

The present study provides encouraging results of growth and survival for pejerrey reared in floating cages for more than 10 months, showing that extensive culture could be implemented beyond post-larval and small juvenile stages. Such results represent an advance in rearing juveniles for long periods of time before releasing them in lakes. However, more information is also needed regarding the influence of stocking size, fish density and culture time in order to optimize extensive cage production. Future studies should compare the advantages of cage culture with intensive and semi-intensive methods taking into consideration economic variables such as market acceptability, flesh quality, cost benefit, etc., and the possibility of extending cage culture to commercial production.

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