Aquaculture Research

Aquaculture Research, 2011, **42**, 754–763 doi: 10.1111/j.1365-2109.2011.02827.x

Growth and feeding of Patagonian pejerrey *Odontesthes hatcheri* reared in net cages

Juan Pablo Hualde[1], Walter Damián Ceferino Torres[1], Pablo Moreno[1], Mirna Ferrada[2], Mariela Ana Demicheli[1], Leonardo Javier Molinari[1] and Carlos Marcelo Luquet[3]

[1]Centro de Ecología Aplicada de Neuquén, Junín de los Andes, Neuquén, Argentina

[2]Centro Regional Universitario Bariloche, Universidad Nacional del Comahue, Bariloche, Argentina

[3]Instituto de Investigaciones en Biodiversidad y Medio Ambiente, Consejo Nacional de Investigación Científica y Tecnológica, Universidad Nacional del Comahue, Bariloche, Argentina

Correspondence: J P Hualde, Centro de Ecología Aplicada del Neuquén, PO Box 7, Junín de los Andes (8371), Neuquén, Argentina. E-mail: pablohualde@yahoo.com.ar

Abstract

An experiment was performed to evaluate the performance of Patagonian pejerrey during net cage rearing in the oligomesotrophic reservoir Exequiel Ramos Mexía. Survival, growth, nutrition and reproduction were evaluated for two lots of pejerrey, initial weights 4.0 and 2.5 g, reared in net cages for 22 and 14 months respectively. Fish were stocked at 29 and 48 individuals m^{-3} densities and fed with an experimental pejerrey feed. During the experiment, temperature fluctuated between 6.6 and 19.6 °C. The two lots did not show substantial differences in survival (pooled survival at the end of the experiment $>80\%$) and the thermal-unit growth coefficient (TGC), daily feed intake and feeding efficiency were 0.43 ± 0.19, 1.70 ± 0.80 and 53.6 ± 9.9 respectively. Digestive tract analysis showed that caged pejerrey can consume substantial quantities of natural food, taking advantage of its planktivorous condition. Pejerrey showed high percentage survival, slow growth and early sexual maturation in captivity. The use of the TGC is proposed as a model for describing the growth pattern of this species and other pejerrey under culture conditions.

Keywords
Patagonian pejerrey, net cage, *Odontesthes hatcheri*, aquaculture, atheriniculture

Introduction

Aquaculture is a constantly growing activity, which constitutes an important source of food of excellent quality. A significant part of this production relies on carnivorous fish and crustaceans, making fish meal and fish oil dominant ingredients in the compound feeds utilized. As these components are mainly obtained from marine fisheries, with most resources being over-exploited, alternative production systems and/or alternative sources of suitable nutrients must be developed. Thus, the farming of low trophic-level fish, which use a higher proportion of vegetal nutrients sources, is recognized as a goal for sustainable expansion of world aquaculture (Naylor, Goldburg, Primavera, Kautzky, Beveridge, Clay, Folke, Lubchenco, Mooney & Troell 2000). The use of native species in aquaculture is a worldwide trend in the search of alternatives for diversification of regional productions and more efficient utilization of available resources. From a biodiversity conservation viewpoint, farming native species could also help avoid negative impacts from introductions of exotic species (Ross, Martinez Palacios & Morales 2008).

Patagonian pejerrey belongs to a group of atherinopsid fish (silversides) widely spread in inland and marine waters of the Americas. Among the freshwater native fish of Argentina, the Patagonian pejerrey (*Odontesthes hatcheri*) and the more popular *Odontesthes bonariensis* are two related species considered to be candidates for aquaculture. Both species provide a tasty flesh of excellent quality, which is highly appreciated both in the local and in the international markets (Somoza, Miranda, Berasain, Colautti, Remes Lenicov & Strüssmann 2008). In fact, *O. bonariensis*, which is naturally abundant in rivers and shallow lakes of the Pampasic region (mainly in

Buenos Aires), has been successfully introduced for recreational fishing in hydroelectric reservoirs and lakes of the center, west and north-west of the country. It has also been introduced to other South American countries like Uruguay, the South of Brazil, Chile, Bolivia and Peru (see Somoza *et al*. 2008, for a review). *Odontesthes hatcheri* inhabits Patagonian rivers and lakes from the Río Colorado basin, 38°59′36″S; 64°05′41″W to Río Senguer 45°30′S; 60°W (Cussac, Cervellini & Battini 1992; Dyer 1993).

The extensive rearing of *O. bonariensis* has been widely practiced in Argentina, Uruguay and South of Brazil, since the beginning of the 20th century, while intensive culture of pejerrey has been developed successfully in Japan during the second half of the century (see Somoza *et al*. 2008 for a review). In recent years, many researchers have worked on the development of culture methods for several Atherinopsidae species (Reartes 1995; Berasain, Colautti & Velasco 2000; Martínez Palacios, Racotta, Ríos Durán, Palacios, Toledo Cuevas & Ross 2006; Miranda, Berasain, Velasco, Shirojo & Somoza 2006; Orellana & Toledo 2007). In contrast, the intensive culture of the Patagonian pejerrey has not yet been evaluated.

The Comahue region in north-west Patagonia possesses seven hydroelectric reservoirs, located on the rivers Limay and Neuquén, covering a surface area of 1220 km^2. The calculated carrying capacity for aquaculture of the three largest reservoirs of the Limay River is 14 900 tonnes $year^{-1}$ (Wicki & Lucchini 2002). However, of these reservoirs, only Alicurá, a 67 km^2 hydroelectric reservoir on the Limay River, is exploited at present, with eight fish farms producing 1400 tonnes $year^{-1}$ of rainbow trout in net cages.

In an important part of the seven reservoirs mentioned above, the summer water temperatures exceed 18 °C, the upper limit of the optimal growth temperature range for rainbow trout (Goddard 1996). O. hatcheri is a good candidate for aquaculture in this region; because it is abundant in all the available reservoirs, and it has great acceptance in regional and international markets. Because pejerrey are planktivorous fish, they are able to feed on natural resources when confined in net cages (Colautti, Garcia de Souza, Balboni & Baigún 2010). This could be an advantageous feature considering that natural food can complement the artificial feed in quantity and in nutrient quality.

The aim of this study was to generate information on the suitability of Patagonian pejerrey for net cage rearing in a typical Patagonian lentic environment, the Ramos Mexía reservoir. For this purpose, we examined the survival, growth, nutrition and reproduction of fish kept for a period of 14–22 months in net cages, where they were fed an artificial diet but also had access to natural food sources. The diet of reared pejerrey was compared with that of conspecific wild fish captured in the same reservoir. The use of the thermal-unit growth coefficient (TGC), as a model for describing the growth pattern of *O. hatcheri* and other pejerrey species, is proposed in this work instead of the specific growth rate (SGR).

Materials and methods

Study site, environmental conditions and rearing cages

Ramos Mexia reservoir is situated in the north of the Patagonian steppe, covering an area of about of 816 km^2 in the Limay River Valley, with a total water volume of 20 150 hm^3. The maximum depth of this reservoir is 64 m (average 24 m) and it is classified as oligomesotrophic (Wicki & Lucchini 2002). During this study, the temperature, dissolved oxygen and transparency were measured daily using a multifunction oxygen metre and a Secchi disc. Total phosphorus and nitrogen were measured seasonally using spectrophotometric methods (Greenberg, Clesceri & Eaton 1992).

The net cages had 6 m length × 3 m width × 4 m height, holding approximately 50 m^3 of water, and were constructed with a 5 mm mesh net. The two cages were supported by a 6 × 6 m raft moored 100 m offshore in a bay 17 m deep. The nets were cleaned weekly in fall, spring and summer and monthly in winter.

Source of fish and rearing conditions

Patagonian pejerrey were obtained from a 5000 m^2 artificial pond located in the CEAN facility (Junín de los Andes Neuquén, Argentina) on two occasions and stocked temporarily in a circular 1000 L tank supplied with abundant water from the Chimehuin River for about 2 months, for observation before transfer to the cages. During this period, the fish were fed an experimental pejerrey feed formulated and preliminarily elaborated in our laboratory; see the description below.

A first lot of 2400 juveniles weighing 4.14 ± 1.3 g (mean ± SD) (lot 1) was transferred to one rearing cage on March 2006. A second lot of 4500 juveniles weighing 2.4 ± 1.3 g (lot 2) was transferred to the other cage on May 2006. Fish were transported in a 500 L tank with a constant O_2 bubbling and a salinity of 5 g L^{-1} NaCl (Tsuzuki, Ogawa, Strussmann, Maita & Takashima 2001). Lots 1 and 2 were reared in the experimental cages for 22 and 14 months respectively. During this period, the fish were hand fed commercially produced experimental pejerrey feed (see the following section) twice a day to satiation, 6 days a week. Occasionally, one or both daily meals had to be cancelled due to strong winds. Fish in lot 1 were fed a commercial feed for trout (see below) during the first 50 days of the experiment due to a delay in the production of the experimental feed for pejerrey. Both lots of fish also had access to naturally available food (plankton) that passed through the net cages.

Preparation of experimental feed

An experimental feed for pejerrey was formulated in our laboratory and order made by a commercial feed manufacturer (Molino Don Antonio SA, General Pico, La Pampa, Argentina). Feed was steamed at 80 °C, pelletized and then dried in a hot air column. Pelletized commercial trout feed was purchased from the same company.

The composition of the experimental feed was determined as follows: total nitrogen (TN) was determined using the Semi-micro Kjeldahl method (AOAC 1990); crude protein was estimated as 6.25 × TN. Crude lipid was measured gravimetrically following extraction of 1 g samples in sulphuric ether, using a Soxhlet apparatus. Moisture was measured gravimetrically, after drying in an oven at 105 °C for 3 h, and ash by combustion in a muffle at 550 °C for 6 h. Total phosphorous was assayed by wet digestion with HNO_3+$HClO_4$ and reaction with ascorbic acid. Soluble phosphorous (fractionated with deionized water) was determined according to Satoh, Viyakarn, Yamazaky, Takeuchi and Watanabe (1992). Nitrogen-free extract was calculated by difference (100 – crude protein – crude lipid – ash – moisture content). Gross energy was calculated at 23.6, 39.5 and 17.2 kJ g^{-1} of protein, lipid and carbohydrate respectively (NRC 1993). The composition of the two feeds utilized in the experiment is shown in Table 1.

Estimation of growth and survival

During the experimental rearing, both groups of fish were monitored and sampled at 29–120-day intervals. Groups of 90–120 fish were anaesthetized with 100 ppm benzocaine and weighed with an electronic balance to the nearest 0.1 g. Feeding efficiency (FE) was calculated as 100 × weight gain (kg)/feed intake (kg). Daily feed intake (DFI) was calculated as 100 × feed intake (kg)/(average body weight × day). Specific growth rate was ($\ln W_2$–$\ln W_1$) day^{-1}. Thermal-unit growth coefficient was calculated according to the following formula (Iwama & Tautz 1981; Cho 1992):

$$\mathrm{TGC} = 1000(W_2^{1/3} - W_1^{1/3})/(T\,D)$$

where W_2 is the final weight (g), W_1 is the initial weight (g), T is the mean temperature for the period (°C) and D is the number of days between measurements.

Mortality was monitored daily, at the time of feeding, and data were grouped to fit in the same schedule of sampling as for growth.

Determination of experimental feed ingestion and natural diet

Caged pejerrey were sampled starting at spring 2006, on several occasions throughout the year, except in winter, in which only one sampling could be made

Table 1 Ingredients and proximate composition of the diets used in this study

Ingredients (g kg^{-1})	Pejerrey feed	Trout feed
Gluten meal	180.0	–
Fish meal	320.0	–
Feather meal, hydrolysate	50.0	–
Soybean meal	200.0	–
Wheat flour	104.0	–
Fish oil	70.0	–
Vitamin premix	15.0	–
Stay C	1.0	–
Sodium chloride	10.0	–
Calcium monobasic phosphate	20.0	–
Bentonite	20.0	–
Choline chloride	5.0	–
Lysine	5.0	–
Proximate composition (g kg^{-1})		
Moisture	93.0	79.0
Protein	452.0	440.0
Lipids	136.0	95.0
Ash	136.0	169.0
Nitrogen-free extract	184.0	215.0
Gross energy (MJ kg^{-1})	19.2	17.9
Total phosphorous	18.8	24.6
Soluble phosphorous	6.6	1.6

–, not indicated in the commercial formula.

(see Table 3) for determination of the amount of experimental feed and natural prey ingested. Fish were sampled at noon, about 3 h after a meal of the experimental diet, and kept in ice until analysis. Digestive tracts were dissected and cut open. Gastric content analysis was performed under a dissection microscope or a light microscope. Alimentary components were classified at the lowest possible taxonomic level. Individuals corresponding to each component were counted and weighed to the nearest 0.1 mg. Chitin remains, which could not be identified, were classified as unidentified Arthropoda (UA). Commercial feed was counted as an alimentary component and treated in the same fashion as the natural components. Algae and Cyanobacteria were classified and described but were not considered for the calculations described below.

Percentage observed frequency: FO% = number of gastric ducts in which a component was present/ total number of gastric ducts analysed.

Alimentary index (AI) (Lauzanne 1975; Rosecchi & Nouaze 1987).

$$AI = (FO\% \times FW\%)/100$$

where FW% = (fresh weight of a component /total fresh weight of the corresponding gastric content) × 100

Table 2 Growth and survival of two lots of Patagonian pejerrey, *Odontesthes hatcheri*, reared in net cages in Ramos Mexía reservoir

	Pejerrey 1	Pejerrey 2
Number of fish	2400	4520
Date	03/29/2006	05/30/2006
Initial weight (g)	4.1 ± 1.3	2.4 ± 1.3
Final weight (g)	120 ± 39	37 ± 14.1
Density (kg m^{-3})	0.2–3.6	0.2–2.8
Period (day)	665	421
TGC	0.44 ± 0.15	0.40 ± 0.25
SGR	1.20 ± 0.80	1.56 ± 1.02
FE	53.6 ± 9.9	ND
DFI	1.70 ± 0.80	ND

TGC, thermal-unit growth coefficient; SGR, specific growth rate; FE, feeding efficiency; DFI, daily feed intake; ND, not determined.

Assessment of the reproductive status

Samples to determine the reproductive status of the caged fish were taken on a monthly basis, from September 2006 to July 2007, except in June. The stage of gonadal development of females was evaluated macroscopically according to the criteria for this group of fish (Grosman 1995). Briefly, seven categories (I–VII) were considered: I (virginal): the gonads show no evidence of past or present activity; II (preparation): gonads show functionality but oocytes are not macroscopically seen; III (maturation): gonad size increased, oocytes are evident; IV (pre-spawning): gonads size highly increased with granulose aspect but spawning cannot be induced by hand; V (spawning) oocytes are clustered around chorionic filaments and are readily released at touch; VI (post-spawning): gonads show a haemorrhagic aspect, isolated and voluminous oocytes and also immature oocytes; and VII (regression): evidence of past spawn-

Table 3 Diet composition of *Odontesthes hatcheri* reared in net cages in Ramos Mexía reservoir

Season	Dietary item	Alimentary index	Observed frequency (%)
Spring (3)	Commercial feed	68.86	74.3
	Insecta	0.14	20.14
	Amphipoda	0.0022	2.94
	UA	2.624	40
Summer (2)	Commercial feed	52.11	56
	Insecta (larvae)	0.649	40
	Crustacea	0.0012	8
	UA	25.44	48
Fall (3)	Commercial feed	7.50	34.25
	Crustacea	13.56	68.76
	UA	36.99	66.6
Winter (1)	Diptera (larvae)	3.461	16.6
	Cladocera	19.06	53.3
	UA	68.89	80

Number of samplings per season is shown between parentheses.
UA, unidentified arthropods.

ing, gonads dark and reduced. The weight increment in male and female gonads was evaluated through the gonadosomatic index (GSI), defined as gonad fresh weight/body fresh weight $\times$ 100.

Statistical analyses

Statistical analyses were performed using BIOSTAT program. The Mann–Whitney non-parametric test was used to compare TGC and SGR, between treatment groups. Results are expressed as mean $\pm$ SD.

Results

Environmental conditions

Transparency, measured as Secchi depth, varied between 2.7 and 9 m according mostly to the precipitation regime and in a lesser degree to plankton productivity. The mean total phosphorous and nitrogen were 18.3 $\pm$ 6.1 and 67.8 $\pm$ 5.7 $\mu g\,L^{-1}$ respectively. The mean pH, conductivity and hardness were 7.0 $\pm$ 0.3, 60 $\pm$ 4.2 mS and 48.2 $\pm$ 9.0 $mg\,L^{-1}$ ($CaCO_3$). Figure 1 shows the average monthly temperature during the study. It can be noticed that between January and March, the water temperature in Ramos Mexía reservoir remains close to 20 °C.

Growth and survival

Patagonian pejerrey lots 1 and 2 were farmed for 22 and 14 months, attaining final mean weights of 120.0 $\pm$ 39 and 37.3 $\pm$ 14.1 g respectively. These fish showed rapid adaptation to the culture conditions, readily accepting artificial diets, and showing good tolerance to disturbing factors such as boat engine noise or movement of workers around the pen. However, interventions in the culture facility, e.g. net cleaning or removal of dead individuals, produced visible changes in fish behaviour such as rapid swimming, sudden movements and loss of appetite. When feed was offered at a low rate, concentrated on a specific point near the centre of the cage, the fish tended to cluster, forming a dense column from 30–50 cm below the surface to near the bottom, showing this behaviour as long as feed was delivered. Satiation was presumed when fish were scattered and swam towards the deepest part of the cage. Whenever the weather allowed us to feed the fish in the described manner, there was almost no feed loss.

The number of fish utilized, the initial and final weights and the duration of the experiment are summarized in Table 2. Mann–Whitney analysis indicated that TGC calculated for pejerrey lots 1 and 2 did not differ significantly ($P = 0.2781$, $U = 10.847$). The pooled mean TGC was 0.43 $\pm$ 0.19, coefficient of variation (CV) = 44%. Specific growth rate did not differ significantly between lots either ($P = 0.1407$, $U = 1.4731$) but showed a higher CV of 65%. The pooled SGR was 1.34 $\pm$ 0.87. Figure 2 shows the growth of pejerrey plotted against time. In Fig. 3, the TGC and SGR values obtained for fish of both groups are plotted against body weight.

The DFI of Patagonian pejerrey was 1.70 $\pm$ 0.80% and FE was 53.6 $\pm$ 9.9%.

Lot 1 pejerrey was fed trout diet during a short period (50 days) at the start of the experiment in cages. Mortality during this period gradually increased up to 0.41% day^{-1}, and decreased to 0.024% day^{-1} when feed was replaced by the pejerrey experimental diet. All dead fish showed deformations in the spine. Lot 2, which was fed only with the pejerrey experimental diet, showed 0.01% mortality day^{-1} and did not show any sign of malformation or change in the mortality rate over time. The percentage survival of both lots for the first 240 days of the study is shown in Fig. 4. It can be noticed that after the first 50 days, when the trout

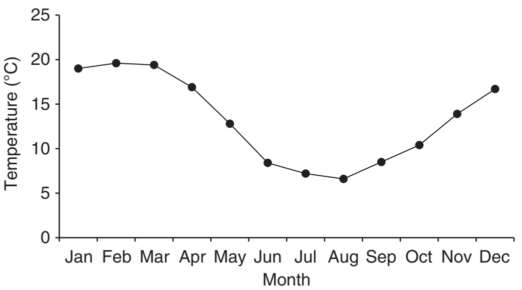

Figure 1 Average water temperature in the Ramos Mexía reservoir during the experiment.

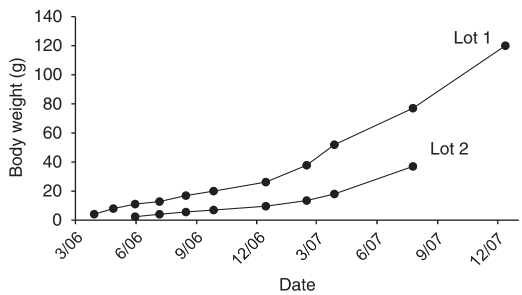

Figure 2 Growth of two groups of Patagonian pejerrey in net cages in the Ramos Mexía reservoir.

feed supplied to lot 1 was replaced for the experimental pejerrey feed, mortality was similar between both lots. Since day 240, mortality data from both lots were pooled and revealed a high percentage survival throughout the experiment. The survival rate, pooling both lots, at the end of the experiment was 87.81%.

Experimental feed ingestion and natural diet

Fish actively ingested the artificial feed throughout the year but the proportion it represented in the diet decreased sharply in fall and winter. The digestive tract content of caged pejerrey was heterogeneous. Besides the commercial feed, planktonic crustaceans accounted for four alimentary components and insects for 6. Additionally, filamentous algae of the genus *Spirogyra sp.* and phytoplankton were common in fish samples. In summer, *Spirogyra sp.* was present in 76% of the digestive tracts. In fall (March), other algal genera such as *Ulotrix sp.*, *Gonium sp. and Coenococcus sp.* were also identified. In April, 60% of the samples contained Cyanobacteria of the genus *Anabaena sp.*

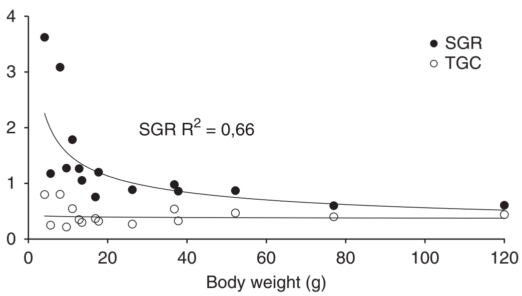

Figure 3 Relationship between body weight and two growth descriptors, SGR and TGC, in Patagonian pejerrey reared in net cages. SGR, specific growth rate; TGC, thermal-unit growth coefficient.

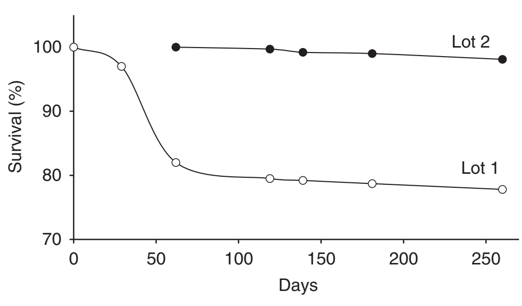

Figure 4 Survival of two lots of Patagonian pejerrey in net cages in the Ramos Mexía reservoir.

Because of calculation problems, the AI refers only to natural components of animal origin plus commercial feed. In spring and summer, the dominant component was the commercial feed, with AI of 68.86 and 52.11 respectively. Another important component in this period was UA (chitin plaques, whose origin could not be identified). In fall, the highest AI (36.99) corresponded to UA. Crustacea was the second most abundant component, with Cladocera as the most representative group (AI = 10.16). In winter, there was only one sampling event in July, in which no commercial feed was detected in the digestive tracts. It must be noticed that this sampling was performed after 5 days during which it was not possible to bring feed to the fish. UA (AI = 68.89) and Cladocera (AI = 19.06) were the most important components in this season. Insects were also present in the diet but in a smaller proportion. Particularly, Diptera larvae were part of the diet in every season, except in fall but always as a rare (AI < 10) component. See Table 3 for detailed results.

The trophic diversity index (Shannon–Wienner, *H*) was 0.91 and de 0.96 in spring and summer respectively. Fall and winter showed much smaller *H* values, 0.16 and 0.41 respectively. For comparison, a single sample of wild Patagonian pejerrey was taken with trawl nets in the coastal zone of the reservoir, near the net cages, in May 2007. The weight of the captured fish ranged from 1.81 to 5.60 g. Cladocera were the dominant component in the diet (AI = 56), while Diptera larvae were present in 75% of the digestive tracts, with an AI of 9. The Shannon–Wiener index of diversity of this sample of wild pejerrey was 0.98.

Reproductive status

The male:female ratio was about 1 in both lot 1 and lot 2 of Patagonian pejerrey. In spring, 71% of the females reached the pre-spawning stage (IV), with a mean body weight of 18.54 g, while in the following winter, 100% of the females reached the same stage, weighing 47.07 g. The smallest female from lot 2 reaching stage IV had 11.5 g body weight and a GSI of 6.92. The mean body weight recorded for stage IV males in spring 2006 and winter 2007 was 15.60 and 40.70 g respectively. Figures 5 and 6 shows the GSI of male and female *O. hatcheri*, respectively, from September 2006 (age 0+) to July 2007 (age 1+). In the first year, peak GSI values were reached in September by males of both lots and in September and December by females of lot 1 and lot 2 respectively. In the second year, both sexes had increasing GSI values already in July when the experiment was terminated.

Discussion

The adaptation of the Patagonian pejerrey to cage farming in Ramos Mexía reservoir was tested through different indicators of growth, feed use, survival and reproductive status.

To describe the growth pattern of *O. hatcheri*, two mathematical models were used in this work. The most widely used model in fish studies is the instantaneous growth rate or SGR, based on the natural logarithm of body weight. Despite its wide use, SGR is recognized as an inappropriate growth model for fish because it decreases with fish size and with the length of the time interval used in the calculation (Iwama & Tautz 1981; Cho 1992). The TGC model was proposed by Iwama and Tautz (1981), and has been shown to well represent the growth curves of several salmonid species. Subsequently, the equation has also been used to describe growth in non-salmonid species, such as common carp, Nile tilapia and marine fish (Kaushik 1998).

One major advantage of TGC is that at a given temperature, it is independent of body weight. In this work, TGC and SGR for Patagonian pejerrey have been calculated for different size ranges, tempera-

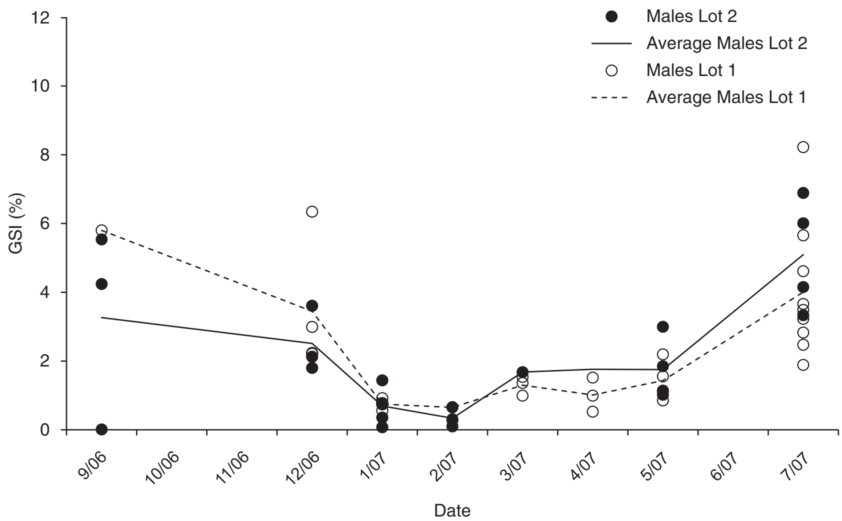

Figure 5 Gonadosomatic index of male Patagonian pejerrey reared in net cages in Ramos Mexía reservoir.

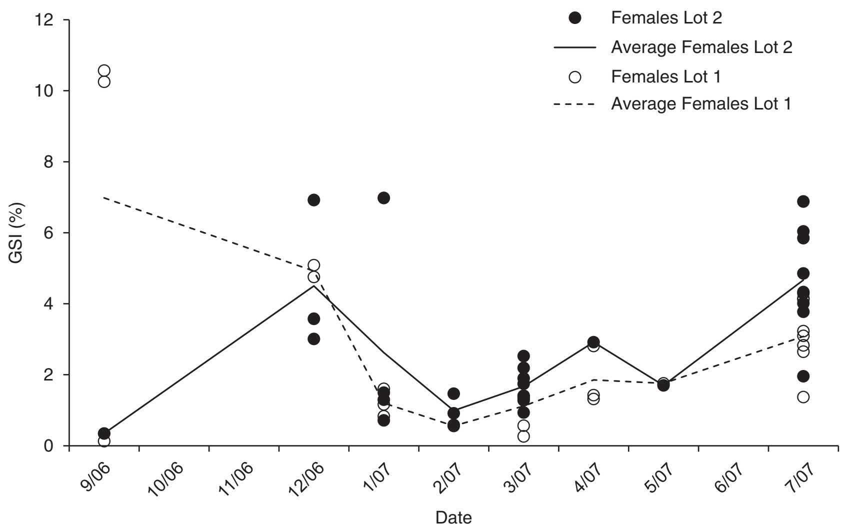

Figure 6 Gonadosomatic index of female Patagonian pejerrey reared in net cages in Ramos Mexía reservoir.

tures and time periods. Figure 4 shows the relationship between body weight and TGC and SGR; whereas SGR decreases with increasing body weight, TGC remains almost constant. These results suggest that TGC rather than SGR should be used to describe the growth pattern of Patagonian pejerrey.

For comparison, we have calculated, from published growth data (Orellana & Toledo 2007; Velasco, Berasain & Ohashi 2008), the TGCs for two other pejerrey species: *O. regia and O. bonariensis* (Table 4). Even when the three species have been reared at different temperatures, salinities and culture conditions, the TGC values are similar. The growth coefficients of these pejerrey species are three to four fold smaller than those of rainbow trout and other salmonid species, but fairly close to those reported for marine species used in aquaculture, which have TGC values ranging from 0.6 to 1.0 (Kaushik 1998).

The growth rates of Patagonian pejerrey are low. The TGC model predicts that, under the experimental conditions of this work, Patagonian pejerrey reach harvest size (220–250 g) after 28 months. Poor growth rate has been considered to be an important biological constraint to cultivation of the pejerrey *O. bonariensis* (Somoza *et al.* 2008). These authors report that the time needed for *O. bonariensis* to reach harvest size ranges from 1.5 to 2.5 years.

Sexual precocity may also have adversely affected both the growth rate and the feed efficiency in the present study, because 70% of females matured sexually at the age of 0+ with about 18 g weight. Slow growth and early maturation are common characteristics of pejerrey, and constrain their suitability for farming (Strussmann, Choon, Takashima & Oshiro 1993). Accordingly, Toda, Toshinami, Yasuda and Susuki (1998) have reported that *O. bonariensis* reaches sexual maturity at the second year of age and exceptionally at the first year.

Another constraint for pejerrey aquaculture reported by several authors in early works reviewed by Somoza *et al.* (2008) is the low survival rate of this fish. This problem was solved for O. bonariensis during the last decades of the 20th century in part by adding 3–5 g L^{-1} NaCl to the water during fish manipulations and acclimatization (Tsuzuki *et al.* 2001). Following this recommendation, we have transported the fish 300 km to the aquaculture facility with negligible mortality and the overall survival rate was high.

Table 4 Thermal-unit growth coefficient (TGC values calculated) for different *Odontesthes* species

Species	TGC	Reference
O. hatcheri	0.43	Present study
O. bonariensis	0.60	Velasco *et al.* (2008)
O. regia	0.54	Orellana and Toledo (2007)

The observed mortality in lot 1 at the beginning of the cage farming cycle could be associated with the low availability of phosphorus in the trout diet used during this period. Preliminary results from our laboratory show that diets poor in soluble phosphorus produce deficiency signs, such as spine demineralization and malformation in Patagonian pejerrey, suggesting a poor absorption capacity for this mineral.

The natural diet study has shown that cage-reared *O. hatcheri* is able to obtain food from the environment, consuming in the highest proportion the principal diet components consumed by wild individuals of the same species. A similar preference for cladocerans and copepods, supplemented by insects when these crustaceans groups were not abundant, was reported for *O. bonariensis* in Japanese lakes (Toda *et al.* 1998). Colautti *et al.* (2010) have demonstrated that juvenile *O. bonariensis* can be reared successfully in net cages in a eutrophic lake without the addition of artificial feed. The plankton productivity of the oligomesotrophic north Patagonian reservoirs is unlikely to support such extensive fish production. However, we have shown that natural diet can replace part of the commercial feed in the intensive system, which may be advantageous for economic and environmental reasons.

The reduction and even the absence of commercial feed in the gastric ducts of caged pejerrey sampled in fall and winter reveals a failure in the feeding method, associated with adverse climatic conditions. Manual feeding was certainly complicated or even impossible during the windiest days. Under such conditions, when little or no artificial feed could be delivered, the uptake of natural food probably supported fish growth but at a low rate. Additionally, these difficulties in delivering feed in the slow but steady manner required by this species probably led to feed wastage. This, together with the lack of nutritional information to produce an adequate feed, can probably explain the low FE recorded in this work (about 53%).

Conclusions

The Patagonian pejerrey shows good adaptation to net cage farming conditions, suffering low mortality. Like other Atherinopsids, *O. hatcheri* exhibits low growth rates and early sexual maturation, which constitute the main drawbacks to its commercial culture. However, the growth rate can be improved by the development of better feeds and feeding methods and by selective breeding and genetic techniques. Our results show that the Patagonian pejerrey may be a good alternative to rainbow trout in reservoirs of Northern Patagonia, where temperatures in summer exceed 20 °C. The ability of pejerrey to efficiently utilize natural food makes it a good candidate for breeding in semi-intensive or intensive, open systems.

Acknowledgments

This study was funded by grants from Ministerio de Ciencia y Tecnología (COFECIT, SECTIP Res. 1028/04; CONICET PIP 6244), Municipalidad de Villa El Chocón and Ministerio de Desarrollo Territorial, Neuquén province, Argentina. The authors are indebted to Mr Miguel León for his support in the operation of facilities and Julio Palacios Foundation for the administration of the COFECIT, SECTIP grant. We thank two anonymous reviewers for greatly improving the manuscript.

References

AOAC (1990) *Official methods of analysis*, Vol. 1, 15th edn. (ed. by K. Helrich), Association of Official Analytical Chemists Inc, Arlington, VA, USA.

Berasain G., Colautti D. & Velasco C.A.M. (2000) Experiencias de cría de pejerrey, *Odontesthes bonariensis*, durante su primer año de vida. *Revista de Ictiología* **8**, 1–7.

Cho C.Y. (1992) Feeding systems for rainbow trout and other salmonids with reference to current estimates of energy and protein requirements. *Aquaculture* **100**, 107–123.

Colautti D.C., Garcia de Souza J.R., Balboni L. & Baigún C.R.M. (2010) Extensive cage culture of pejerrey (*Odontesthes bonariensis*) in a shallow pampean lake in Argentina. *Aquaculture Research* **41**, 376–384.

Cussac V., Cervellini P. & Battini M. (1992) Intralacustrine movements of *Galaxias maculatus* and *Odontesthes hatcheri* during their early life history. *Environmental Biology of Fishes* **35**, 141–148.

Dyer B.S. (1993) *A Phylogenetic study of Ateriniform fishes with a systematic revision of the South American silversides (Atherinomorpha, Atherinopsinae, Sorgentinini)*. PhD thesis, University of Michigan, 596pp.

Goddard S. (1996) *Feed Management in Intensive Aquaculture*. Chapman & Hall, New York, 194 pp.

Greenberg A.E., Clesceri L.S. & Eaton A.D. (1992) *Standard Methods for the Examination of Water and Wastewater*, 18th^{h} ed. APHA, Washington, DC, USA.

Grosman F. (1995) *El pejerrey. Ecología, cultivo, pesca y explotación*. Editorial Astyanax, Buenos Aires, Argentina, 132pp (in Spanish).

Iwama G.K. & Tautz A.F. (1981) A simple growth model for salmonids in hatcheries. *Canadian Journal of Fisheries and Aquatic Sciences* **38**, 649–656.

Kaushik S.J. (1998) Nutritional bioenergetics and estimation of waste production in non-salmonids. *Aquatic Living Resources* **11**, 211–217.

Lauzanne L. (1975) Régime alimentaire d'Hidrocyon forskali (Pisces:Characidae) dans le lac Tchad et ses tributaries. Cahiers ORSTOM. *Série Hydrobiologie* **9**, 105–121.

Martínez Palacios C.A., Racotta I.S., Ríos Durán M.G., Palacios E., Toledo Cuevas M. & Ross L.G. (2006) Advances in applied research for the culture of Mexican silversides (*Chirostoma*, Atherinopsidae). *Biocell* **30**, 137–148.

Miranda L.A., Berasain G.E., Velasco C.A.M., Shirojo Y. & Somoza G.M. (2006) Natural spawning and intensive culture of pejerrey *Odontesthes bonariensis* juveniles. *Biocell* **30**, 157–162.

Naylor R., Goldburg R., Primavera J., Kautzky N., Beveridge M., Clay J., Folke C., Lubchenco J., Mooney H. & Troell M. (2000) Effect of aquaculture on world fish supplies. *Nature* **405**, 1017–1024.

NRC (1993) *Nutrient Requirements of Fish*. National Academy Press, Washington, DC, USA, 114pp.

Orellana A. & Toledo H.E. (2007) Growth of juvenile marine silverside (*Odontesthes regia* Humboldt, 1821) (Atherinidae) in sea net pen cages. *Gayana* **71**, 76–83.

Reartes J. (1995) El pejerrey (*Odontesthes bonariensis*): métodos de cría y cultivo masivo. *COPESCAL (FAO) Documento Ocasional* **9**, 1–35.

Rosecchi E. & Nouaze Y. (1987) Comparaison de cinq indices alimentaires utilisés dans l'analyse des contenus stomacaux. *Revues des Travaux de I'Institut des Pêches Maritimes* **49**, 11–123.

Ross L.G., Martinez Palacios C.A. & Morales E.J. (2008) Developing native fish species for aquaculture: the interacting demands of biodiversity, sustainable aquaculture and livelihoods. *Aquaculture Research* **39**, 675–683.

Satoh S., Viyakarn V., Yamazaky Y., Takeuchi T. & Watanabe T. (1992) A simple method for determination of available phosphorous content in fish diet. *Nippon Suisan Gakkaishii* **58**, 2095–2100.

Somoza G.M., Miranda L.A., Berasain G.E., Colautti D., Remes Lenicov M. & Strüssmann C.A. (2008) Historical aspects, current status, and prospects of pejerrey aquaculture in South America. *Aquaculture Research* **39**, 784–793.

Strussmann C.A., Choon N.B., Takashima F. & Oshiro T. (1993) Triploidy induction in an Atherinid fish, the pejerrey (*Odontesthes bonariensis*). *The progressive Fish Culturist* **55**, 83–89.

Toda K., Toshinami K., Yasuda N. & Susuki S. (1998) *Cultivo del Pejerrey en Japón*. Asociación Argentino-Japonesa del Pejerrey, Buenos Aires, Argentina, 69pp.

Tsuzuki M.Y., Ogawa K., Strussmann C.A., Maita M. & Takashima F. (2001) Physiological responses during stress and subsequent recovery at different salinities in adult pejerrey *Odontesthes bonariensis*. *Aquaculture* **200**, 349–362.

Velasco C.A., Berasain G.E. & Ohashi M. (2008) Producción intensiva de juveniles de pejerrey (*Odontesthes bonariensis*). Instituto de Limnología "Dr. R.A. Ringuelet". *Biología Acuática* **24**, 53–58.

Wicki G.A. & Lucchini L. (2002) *Evaluación del potencial para acuicultura en la región del Comahue. (Provincias de Neuquén y Río Negro). Información Básica*. Secretaría de Agricultura, Ganadería, Pesca y Alimentos (SAGPyA), 52pp.