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Assessment of condition in pejerrey *Odontesthes bonariensis* (Atheriniformes: Atherinopsidae) populations: which index works best?

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The pejerrey *Odontesthes bonariensis* is the most important target species in temperate freshwater fisheries of Argentina, and assessment of condition has been a regular practice and common diagnostic tool. Most pejerrey fishery studies have used Fulton's (K) index, without testing whether underlying assumptions or requirements were met. We analyzed and contrasted the applicability of K, Kn and Wr indices to assess condition status in several pejerrey populations inhabiting Pampean lakes. Our results showed that whereas Wr and Kn displayed significant condition changes across length at some study lakes, Kn portrayed a small range of variation. We also noted that pejerrey maximum length and size structure strongly varied among populations probably due to the characteristics of trophic niche changes through lifespan, depending on lake limnological characteristics and zooplankton availability. We conclude that the K index should be disregarded in those cases where populations show allometric growth and size ranges strongly vary. In turn, the Kn index appears to be only appropriate for regular within population assessment, being difficult to apply when comparisons between populations are needed and when they exhibit different weight-length relationship slopes. Finally, the Wr index should be strongly preferred if the objective is to perform comparisons between pejerrey populations, particularly when population structure is not well known, stocking has been used for population recovery, lakes are strongly supported by limnological changes, data are limited to only one or few samplings and metaphoetesis is suspected in pejerrey populations.

O peixe-rei *Odontesthes bonariensis* é a espécie mais importante na pesca de água doce da região temperada da Argentina, e a avaliação de sua condição corpórea tem sido uma prática normal e uma ferramenta de diagnóstico bastante utilizada. Grande parte dos estudos sobre a pesca do peixe-rei utiliza o índice de Fulton (K), sem testar se seus pressupostos são atendidos. Nós analisamos e comparamos a aplicabilidade dos índices K, Kn e Wr para a avaliação do fator de condição em várias populações de peixe-rei em lagos dos Pampas. Nossos resultados mostram que, enquanto o Wr e o Kn dependeram significativamente do comprimento corporal em alguns lagos, o Kn apresentou uma pequena amplitude de variação. Foi também notado que o comprimento máximo e a estrutura de tamanho variaram fortemente entre populações, provavelmente devido às mudanças ontogenéticas no nicho trófico, dependendo das características limnológicas e da disponibilidade de zooplâncton. Concluímos que o índice K deve ser desconsiderado nos casos em que as populações apresentam variações alométricas marcantes no crescimento e na amplitude de tamanhos. O índice Kn parece ser apropriado apenas para avaliações de uma única população, não sendo apropriado para comparações entre populações quando elas exibem diferentes inclinações na relação peso-comprimento. Finalmente, o índice Wr é recomendado se o objetivo for fazer comparações entre populações de peixe-rei, particularmente quando a estrutura populacional não é bem conhecida, a estocagem tenha sido usada para a recuperação populacional, os lagos apresentam grandes variações limnológicas, os dados se limitam a uma ou poucas amostras e suspeita-se da ocorrência de mudanças ontogenéticas na dieta.

Key words: Fish plumpness, Pampean lakes, Fishery management.

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Introduction

A common practice in freshwater fisheries biology is to scrutinize fish condition as an indicator of well being and for comparing populations or stocks. Condition indices portrayed by morphometric measurements represent a basis for developing an explanatory hypothesis about biological responses or different ecological scenarios for populations (Liao *et al*., 1995). Several indices have been proposed in the literature (Bolger & Connolly, 1989) and reviewed by Froese (2006). Physiological indices such as hepatosomatic, mesenteric and visceral indices represent a direct measure of fish nutritional status, whereas indirect indices such as condition factor, relative condition factor and relative weight provide external measurements of overall health (Brown & Murphy, 2004). Such indices have been widely used as indicators of the nutritional state of fish (Gutreuter & Childress, 1990), assuming that condition changes are a consequence of physiological or ecological alterations (Sutton *et al*., 2000). Some constraints for the application of condition indices are obvious, but several limitations are more subtle and are therefore usually ignored.

Condition assessment has been a regular practice and has been applied as a diagnostic tool for pejerrey (*Odontesthes bonariensis*) population surveys (Freyre, 1976). The pejerrey is the most valuable target species in most of the warm temperate lakes and reservoirs of Argentina. This species originally inhabits lakes and lagoons of Pampean region (Argentina) and Rio Grande do Sul, Brazil (Dyer, 2006), but has also been successfully stocked in other basins of Brazil, Argentina and even other South American countries due to its fishing values. The high quality of pejerrey has also encouraged its culture in places far from its native distribution range, such as Japan and Italy (Somoza *et al*., 2008).

Most pejerrey studies have focused on the use of Fulton's (K) index (Ricker, 1975) and the cephalic index (Ringuelet, 1964). The K index has been used, for example, by Freyre *et al*., (1969) in Chascomús, Salada Grande, El Carpincho, Monte, Alsina and Cochicó lakes and by Grosman & Sergeña (1996) in the Encadenadas de Tornquist lakes. Several other examples are found in technical reports prepared by the Undersecretary of Fishing Activities of Buenos Aires province (http://www.maa.gba.gov.ar/pesca/index.php), which performed regular surveys in different lakes for several years. Since some of these surveys were carried out on a punctual basis, even comparing condition among populations from different lakes, it seems necessary to clarify the constraints of using condition indices based on the characteristics of samples and populations. Other alternatives such as relative weight (Wr) (Wege & Anderson, 1983) have been neglected or ignored, despite the fact that such index has become popular in assessing North American fish populations (Blackwell *et al*., 2000). For pejerrey, Baigún & Anderson (1994) provided for the first time the required standard relationship for the species, whereas Colautti *et al*. (2006) developed a standard regression for only Pampean lake populations.

The increasing importance of pejerrey recreational fisheries and the development of some commercial fisheries in large shallow Pampean lakes have challenged managers and biologists to provide comprehensive management guidelines and cues for assessing pejerrey population status. This is a critical issue since Pampean lakes exhibit highly dynamic changes in their trophic status related to natural hydrological modifications associated with rain cycles (López *et al*., 2001). Such modifications may affect pejerrey populations by changing recruitment, mortality, growth patterns, food availability and, ultimately, body condition. Since rapid assessment methods for pejerrey population have included condition estimates as a regular and effective diagnostic method, even outside Pampean lakes and also for culture purposes, it is therefore essential to review and define how well different indices portray population condition under different ecological scenarios and population characteristics.

The aim of this study was to analyze and discuss the application of the most common condition indices used for pejerrey populations in Pampean lakes, testing their application for regular fish population assessment. We also analyze here how lake ecological characteristics may influence condition assessments and how interpretation may be affected by intrinsic index characteristics.

Material and Methods

During January-February 2004, we sampled pejerrey populations from eight Pampean lakes located in Buenos Aires Province (Fig. 1). At each lake, three sites (inshore and open waters) were sampled using two sets of standardized gill-net with mesh sizes of 30, 38, 42, 50, 60, 66, 76 and 80 mm) measured between opposite knots, each with a length of 25 m, and a seine beach net, with the aim of obtaining representative samples of fish populations and fish community. Capture per unit effort was estimated from gill nets considering one fishing night (12 h) as a standard effort unit and mesh size (Baigún, 1989).

The weight (W), standard length (SL) and total length (TL) of the fishes were measured with 1 g or 1 mm precision. Thirty pejerrey stomachs were collected per lake and preserved in 10% formalin for determining food items. In order to test pejerrey condition for each population and to compare the results, we applied different indices as summarized below:

a) Fulton's condition index (K):

Fulton's index (Ricker, 1975) is the ratio of the observed weight (W) at a specific length with respect to a fish whose length (L) increases following a cubic (isometric) relationship (Ricker, 1975). The formula for this index is:

$$K = (W/L^3).C$$

where C is a constant, usually 10^5 when metric units are used.

b) Relative condition factor (Kn) Le Cren (1951):

$$Kn = W/We$$

where (We) is the length specific mean weight predicted by the population weight-length relationship, *i.e*., We = a L^b, where a and b are the regression coefficients. Unlike the Fulton index, the Le Cren index considers that weight could increase in an allometric way if b differs from 3. The Kn index represents the true population variation around the mean condition value independent of fish size, allowing comparisons of different fish from the same sample, independent of length.

c) Relative weight (Wr):

This index, originally developed by Wege & Anderson (1978), represents a refinement of Kn and is defined as the ratio of the weight (W) of a fish to the length specific standard weight (Ws) predicted by a weight-length regression for the species, which must be obtained using the regression-line-percentile (RLP) developed by Murphy *et al*. (1991). Unlike the simple regression required by the Le Cren index, RLP uses data from different populations fitting a curve to the 75th-percentile weights and must meet several requirements (Murphy *et al*., 1990; Brown & Murphy, 1996). Such constraints were considered by Colautti *et al*. (2006), who developed a standard regression for pejerrey in Pampean lakes. In accordance with these authors, we used 12 cm as the minimum reliable size for pejerrey Wr estimation.

$$Wr = (W/Ws).100$$

The Ws value derived from a standardized equation represents the weight of a fish exhibiting better than average for a given species. According to Anderson & Gutreuter (1983), a Ws value of 100 ± 5 should be considered indicative of an optimum condition within a physiological and ecological framework. Baigún & Anderson (1994) defined a standard regression based on populations inhabiting temperate lakes and reservoirs of Argentina. However, to estimate Ws values, we used the equation presented by Colautti *et al*. (2006) established for only Pampean pejerrey populations using the regression-line-percentile technique (Murphy *et al*., 1990). This equation that predicts weight from standard length is:

$$\log Ws = 5.2669 + 3.1625 \log SL$$

To determine if index values were related to fish length, we tested the significance of the slope regression between all pooled data. We also estimated mean values and their respective coefficient of variation by length interval and pooled lengths for each lake. Length intervals were obtained from Baigún & Anderson (1994) who defined a stock, preferred, quality, memorable and trophic length range. Total length determined by these authors was transformed to standard length. However, we added a substock group which was defined as the number of fish between 12 cm and 21 cm standard length. To determine the trends in variation of each index as a function of length, we plotted the individual index data and displayed also the average index values for each length category by lake. Finally, to assess size distribution and its potential effect on condition, we also estimated a proportional reproductive stock index (PRS). The PRS is defined as the ratio between the number of pejerrey larger than 21 cm (Ls) and the number of pejerrey equal to or larger than 12 cm. The PRS is conceptually equivalent to the proportional stock density index (Anderson, 1980) and is a suitable indicator of size distribution within a population.

Also, general limnological characteristics were obtained by measuring conductivity, dissolved oxygen and lake area (Table 1). Zooplankton composition at each lake was also characterized by estimating the abundance of cladocerans and copepods (macrozooplankton) and determining the qualitative food items in pejerrey stomachs. Samples were taken in at least two locations per lake by filtering twenty liters each in order to determine organisms/l using the methods described in Paggi & Paggi (1995).

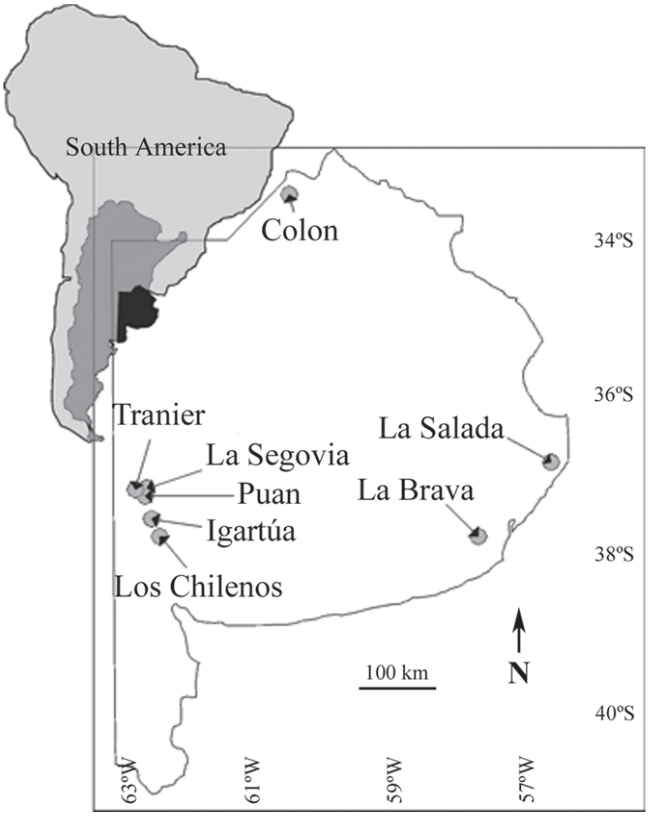

Fig. 1. Geographical location of sampled lakes in the Pampean region of Argentina.

Results

The study lakes differed in general limnological characteristics displaying the mosaic of environmental conditions usually exhibited by Pampean lakes. Also, general fish abundance and pejerrey composition varied according to lake (Table 1). In turn, Table 2 exhibits the parameters a (intercept), b (regression coefficient), r (correlation coefficient), and N (number of specimens analyzed) of the length-weight relationships, whereas statistical parameters of the indices used are shown in Table 3. Mean K index showed values greater than 1 in almost all lakes, whereas mean Wr exhibited values smaller than 100 except in only one lake. A Wr between 95 and 100 has been considered indicative of good condition in the literature (Wege & Anderson, 1978). In turn Kn values ranged around 1 and, as expected, exhibited the lowest variation.

In a first attempt to determine to what extent condition indices vary across length, we analyzed the relationship between the different indices and pejerrey length for the pooled populations (Fig. 2). Only the K-length regression showed a significant correlation and slope ($r = 0.32$; $p < 0.0001$). However, since K has been the most used index but at the same time has demonstrated instability due to ignoring allometric growth, we explored in more detail to what extent condition values were affected across length in individual lakes (Fig. 3). In Colon and Igartua lakes, the general condition of fish was good, where Wr and Kn followed a similar trend but differed from K. In Puan and Los Chilenos lakes where both K and Wr increased with length, the K slope was larger and population values showed a broader range compared to Wr. For both indices, there was a large contrast between substock and memorable fish size condition, changing for instance the K index from 0.9 to 1.84 and Wr index from 74 to 125 in Los Chilenos Lake. In turn, Kn did not show a significant variation across length. In both lakes, pejerrey populations were dominant and those individuals larger than 200 mm showed a piscivorous diet, with condition values being above the average condition and the highest among sampled populations. In La Salada Lake, Wr and K exhibited the lowest mean values, which can be related to very low zooplankton abundance and lack of piscivory. Finally, in Segovia and Tranier lakes, all indices showed same variation in profiles. The K and Wr indices assumed high mean values suggesting a good condition across length. Nonetheless, Kn remained around one, and followed closely the Wr variation due to the b parameter of the weight-length equations being very similar to the b of the pejerrey standard weight equation. In both lakes, pejerrey appeared as the highly dominant species with zooplankton abundance also being high.

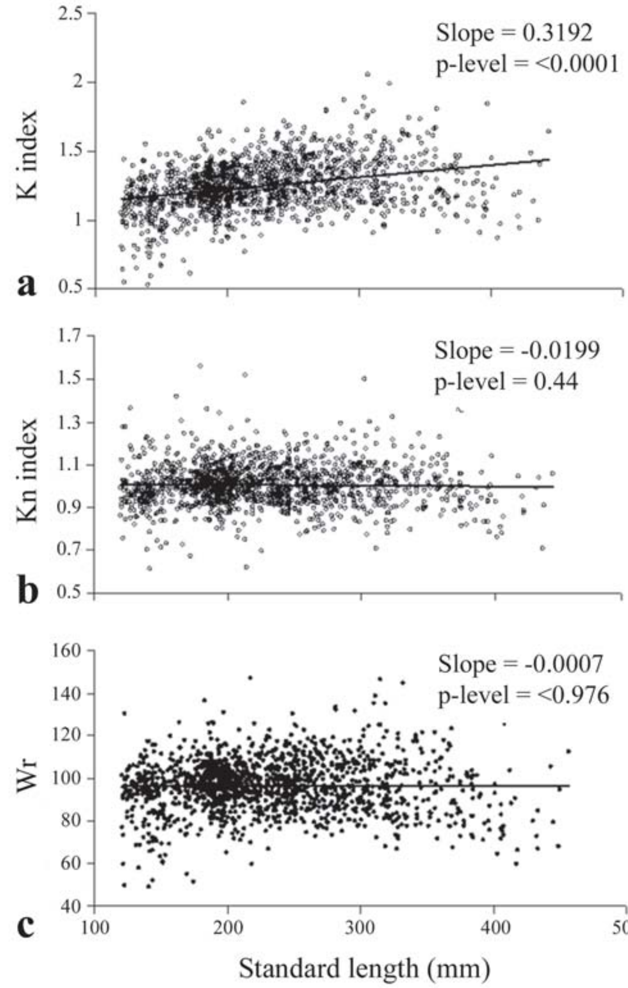

Fig. 2. Relationship between standard length and (a) K index, (b) Kn index and (c) Wr index for pejerrey populations in Pampean lakes.

Discussion

In this paper, we tested the ability of different indices to assess pejerrey condition in Pampean lakes. We compared the application of such indices during the summer period when pejerrey populations do not exhibit reproductive patterns, thus removing the effects of gonad development on fish weight. Condition indices have been historically used by biologists as surrogate indicators of changes in physiological characteristics related to bioecological factors. In Pampean lakes by far, the K index has been used as the main index for assessing pejerrey populations relating condition with trophic conditions, and spawning periods. Moreover, some previous studies presented K values associated with their confidence limits across length as suggested by Freyre (1976) to determine departures from

Table 1. Limnological characteristics and pejerrey population features in study lakes. Z: zooplankton; F: fish; I: insects. PRS: proportional reproductive stock. CPUE: catch per unit effort.

Lake	Colon	Igartua	La Brava	Segovia	Puan	Los Chilenos	Tranier	La Salada
Area (ha)	36	51	420	89	793	450	57	5500
Conductivity (µS/cm)	5970	1980	963.3	2210	3380	1500	624	6896
Zooplankton (individuals $x10^{-3}$/100L)	1.38	150	176.44	217.73	42.68	17.6	150.63	12.5
Species richness	9	5	6	3	2	7	2	6
CPUE	24.30	28	43.13	14.52	12.63	4.22	52.60	37
Pejerrey population characteristics								
PRS	31.5	48	97	37	50	27	58.4	47
% pejerrey	19.7	99.5	51.93	95	97.7	87.5	99.5	66.5
Food items <200mm	Z I	Z	Z I	Z I	Z	Z	Z	Z
Food items >200mm	F	Z	Z	Z F	F	F	Z	Z

Table 2. Estimated parameters of the weight-length-relationships for the studied lakes. N: number of sampled fish; a: intercept; b: regression coefficient; r: correlation coefficient.

Lake	N	a	b	r^2
Tranier	196	-5.176	3.136	0.992
Puan	160	-5.971	3.440	0.994
Los Chilenos	162	-6.371	3.604	0.988
La Segovia	117	-5.245	3.147	0.976
La Brava	190	-4.972	3.006	0.986
Igartua	391	-5.066	3.071	0.978
Colon	176	-5.107	3.080	0.988
La Salada	137	-4.788	2.890	0.993

Table 3. Statistical parameters of K, Kn and Wr indices in sampled lakes. SD: standard deviation.

Index	Colon	Igartua	Puan	Los Chilenos	La Brava	La Salada	La Segovia	Tranier
Mean Wr	94.17	97.82	89.04	81.34	80.60	70.64	97.07	107.13
Max Wr	117.45	146.86	123.33	125.40	104.92	82.61	120.39	126.17
Min Wr	69.28	59.88	71.01	48.79	59.69	59.84	66.81	86.98
SD Wr	8.33	7.81	11.84	17.29	7.09	5.601	11.85	8.15
Mean K	1.18	1.24	1.16	1.04	1.10	0.99	1.27	1.37
Max K	1.54	1.85	1.80	1.84	1.43	1.00	1.67	1.65
Min K	0.84	0.77	0.86	0.53	0.87	0.82	0.89	1.01
SD K	0.13	0.11	0.23	0.30	0.10	0.053	0.17	0.13
Mean Kn	1.00	1.00	1.00	1.01	1.00	1.00	1.01	1.00
Max Kn	1.23	1.51	1.26	1.36	1.29	1.10	1.25	1.18
Min Kn	0.73	0.62	0.79	0.67	0.78	0.90	0.69	0.82
SD Kn	0.09	0.08	0.09	0.14	0.08	0.053	0.12	0.08

average conditions. However, most of these studies obtained unrealistic condition values since slope of weight-length relationship was rarely isometric (b = 3). For example, slopes from weight-length relationships computed from 74 pejerrey populations in different lakes or time periods presented by Colautti *et al*. (2006) showed that most slope values were not isometric (b > 3) and above 3 (Fig. 4). In fact, isometric slope only represented 16% of study cases, demonstrating that a slope of b = 3 is a common assumption that was mostly not fulfilled, ranging in our study lakes from 2.89 to 3.60. A major limitation for K index use is its inability to compare condition between populations unless similar length intervals are used. Length dependence by this index is easy to demonstrate by replacing W by its respective length relationship (aL^b) in the index formula. Clearly, if length increment is isometric, K is defined by only the parameter "a" and therefore becomes length independent; otherwise, length dependence becomes positive or negative according to the b = 3 value. We propose that K is only appropriate for indexing fish of close length and populations where b = 3, which may be quite uncommon in Pampean lakes. Using maximum length as proxy for infinite length (Froese & Binohlan, 2000), it is apparent that growth strongly varies among populations from 27 to 53 cm (Fig. 5), probably depending on zooplankton quality and limnological differences between lakes. Moreover, even within the same population, the weight-length relationship slope showed a noticeable variation over years (Fig. 6).

Le Cren's Kn index relaxes length dependence, but this index appears suitable for species or body waters where populations should have the same slope (b) in the weight-length relationship (Bolger & Connolly, 1989). However, the b coefficient changes with season (Lima *et al*., 2002) and populations, thus precluding proper analysis. Our results showed that whereas Wr and K displayed significant condition changes across length in some study lakes, Kn showed a small variation range (0.9-1.1). This feature indicates that Kn exhibits low sensitivity to portray condition differences, particularly for large-size species.

Such constraints are probably a main limitation for pejerrey population assessment on a regional scale, since lakes strongly differ in terms of ecological characteristics, thus influencing fish bionomic features (growth, length, weight). Moreover, its application would not be recommended where only punctual or occasional surveys are performed. As proposed by Froese (2006), the Kn index should be used only within samples, and it could be useful and applicable where species condition is monitored for long time periods in the same population. However, it could be indicative of spawning period and/or decrease in foraging activity (Gomiero & Braga, 2005). Since in Pampean lakes, managers are often interested in allocating both recreational and commercial activity, Kn index appears to be of little value to support decisions based on length or growth comparisons among lakes.

In turn, Wr application has not been a common practice

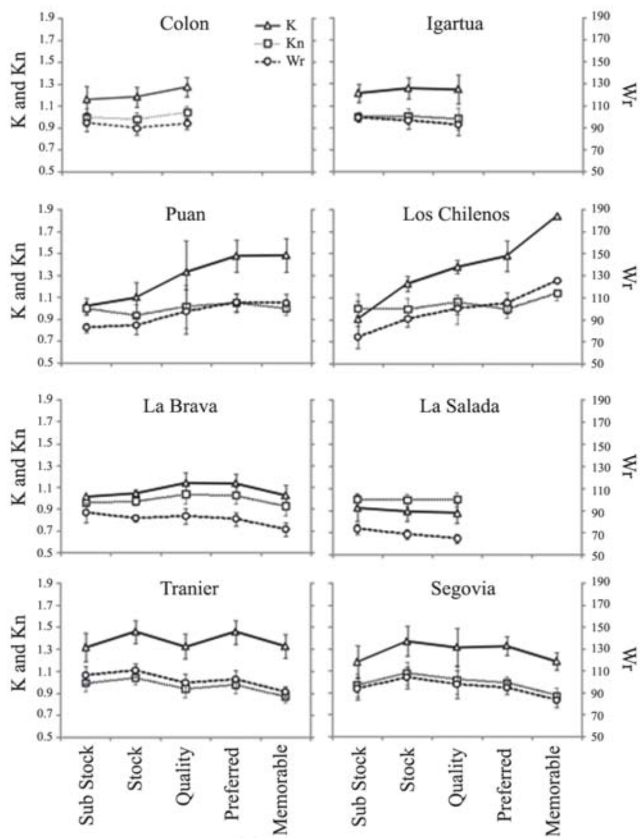

Fig. 3. Relationship between K, Kn and Wr values and length intervals for study lakes.

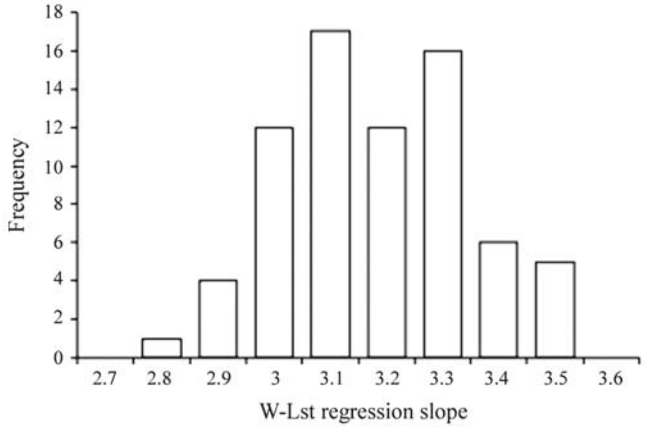

Fig. 4. Distribution of weight-length regression slopes of 74 sampled populations (adapted from Colautti *et al*., 2006).

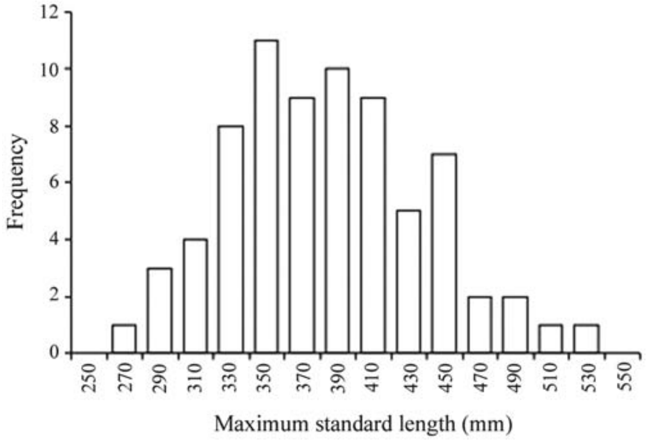

Fig. 5. Distribution of maximum standard length from 74 sampled populations (adapted from Colautti *et al*., 2006).

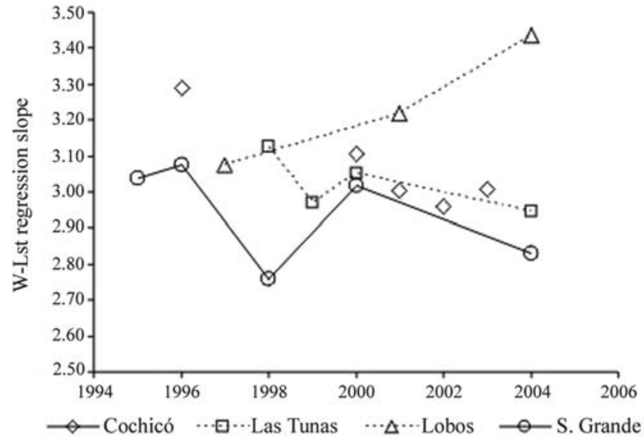

Fig. 6. Variability of weight-length regression slopes within lakes sampled at different years (adapted from Colautti *et al*., 2006).

for assessing and comparing pejerrey populations, although a standardized weight-length relationship was available (Baigún & Anderson, 1994). Recently, Colautti *et al*. (2006) proposed a new relationship based only on Pampean populations, taking into account main requirements for properly establishing such equation (Murhy *et al*., 1990; Brown & Murphy, 1996). Relative weight can be related to biological features such as growth, prey availability, population density, stocking density, P/B ratio, fishing regulations, hydrological variations, water quality, etc (see Blackwell *et al*., 2000 for review). In the case of pejerrey, Wr was related to length structure indices (Baigún & Anderson, 1994) and CPUE (Colautti *et al*., 2006), showing its potential as a reliable tool for measuring fisheries response to management regulations. An additional advantage of Wr but not found in other condition indices is that management objectives can be recommended based on target values (Murphy *et al*., 1991). Yet, Wr would not be free of constraints, and some authors cautioned about its length dependence (Murphy *et al*., 1990; Willis *et al*., 1991; Cone, 1989, 1990; Hansen & Nate, 2005). However, Neuman & Murphy (1991) considered that Wr variation as a function of length can be attributed to different bioecological characteristics. In our study, we adopted length interval criteria according to Baigún & Anderson (1994) guidelines, by assuming that length intervals should have some fisheries meanings (Murphy *et al*., 1990). We propose that zooplankton quantity and quality are a major factor influencing pejerrey body condition (Colautti *et al*., 2003). Unlike other Pampean fish species, pejerrey can modify its trophic niche, where adult growth depending on zooplankton structure and fish prey abundance changes from strictly zooplanktivorous to piscivorous through its lifespan (Ringuelet *et al*., 1980; Escalante, 2001). In Puan and Los Chilenos, for example, pejerrey larger than 200 mm showed a piscivorous diet and the largest condition as reflected by both K and Wr indices but not by Kn. In such cases, it was not unexpected that Wr may be related to length as trophic niche changes according to growth. This effect should be reflected by condition changes, and thus we encourage estimating condition indices by length intervals when possible.

We conclude that although condition indices will still be used as diagnostic and assessment tools for pejerrey populations due to their simplicity, their application should be considered with caution taking into account their advantages and inherent limitations. Fulton's index should be disregarded in those cases where populations show allometric growth and where size range strongly varies, as seems to be the case for most of the pejerrey populations reviewed. The Kn index appears to be only appropriate for regular within population assessment and therefore of more limited utility, where it is difficult to apply when comparisons between populations are needed and when they exhibit different weight-length relationship slopes. The Wr index should be strongly preferred in regular surveys if the objective is to perform comparisons between pejerrey populations, particularly when population structure is not well known, stocking has been used for population recovery, lakes are supported strongly by limnological changes, data are limited to only one or few samplings, and metaphoetesis is suspected in pejerrey populations. We believe that the Wr index is better than K since it minimizes the skewness due to length effect and is preferable to Kn because it portrays the condition not only at the population level but also from a species perspective.

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