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Variation over Time of Length–Weight Relationships and Condition Factors for Four Exotic Fish Species from a Restored Shallow Lake in NE Iberian Peninsula

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Abstract: Length–weight relationships (LWRs), condition factors, and their variation over time were analyzed for four exotic freshwater fish (bleak, common carp, pikeperch, and roach) in the Estany d'Ivars i Vila-sana shallow lake in Catalonia, Northern Spain. Fish samples were collected twice a year (early summer and autumn), between 2008 and 2016, by using between three and five multi-mesh nylon gillnets. This study provides novel information about four common exotic fishes outside of their natural range and within the context of a restored shallow lake, where the ichthyologic community is evolving in concordance with the ecosystem conditions and the fish community dynamics.

Keywords: alien invasive species; long-term monitoring; LWR; condition factor; Mediterranean

1. Introduction

The analysis of length–weight relationships (LWRs) and condition factors are common tools in studies of fish biology, ecology, and physiology, and they have been extensively used in fishery research and management [1–4]. LWRs enable the picturing of a specific population, irrespective of individual variation giving an idea of the condition [5] and fitness of the population [4]. They are also essential for stock biomass assessment [5,6], studies on population dynamics, and fish stock assessment and monitoring [7]. Furthermore, LWRs allow analyses of life histories, growth patterns, and comparative morphology of different fish species, or populations, from different habitats and/or regions and environmental conditions [2]. In fact, estimates for the same species in different regions can be modified by environmental conditions or the developmental state of the fish [5], becoming a tool to evaluate fish condition. Condition indices, such as Fulton's condition factor (*Ki*), LeCren's relative condition factor (*Kn*), and others, have been derived from LWR, and have been powerful instruments in fisheries science [1,4]. Thanks to these features, within the framework of long-term studies, we hypothesized that changes in the LWR slope and condition indices reflect changes of fish condition, the potential causes of which have their origin in alterations on the ecosystem and/or the ichthyologic community. Despite the usefulness of LWRs, their availability is incomplete and frequently limited to the most common and more studied fish species [8]. Moreover, LWRs are rarely used as a dynamic concept, as if describing factors remain unaltered over time and are characteristic of an ecosystem. However, LWR variation could be a useful tool to evaluate the effects of ecosystem changes on a fish community. Therefore, a significant lack of knowledge of the ecological responses of fish communities to the intrinsic dynamics of restored ecosystems still exists, and research is necessary to better understand, model, and manage this kind of process.

LWRs and condition indices of exotic species are essential tools within management and fish community monitoring contexts, and they allow for the evaluation of the state of the populations. Nonetheless, there are no cases of using LWRs to evaluate and monitor fish communities within the context of a recently restored ecosystem during long-term monitoring. To fill these gaps and contribute to the science and management of exotic fish communities in these ecosystems, we investigated the status of fish communities in a restored shallow lake in the NE Iberian Peninsula by analyzing the variation of LWRs over time and their differences between seasons.

The Estany d'Ivars i Vila-sana is an endorreic ecosystem that was artificially dried in 1951 and converted to agricultural land. Restoration started in 2005, and the lake reached its current water level in 2008, using water from the Urgell irrigation channel (Canal d'Urgell). Due to the lack of hydrological connection with any river, natural recolonization was unexpected. However, the presence of introduced fishes was detected in 2007, just one and a half years after restoration. One year later, in 2008, monitoring of fish stocks began.

Here, we estimated the LWRs—in our case, the fork length (FL)—and an analysis of their variation, and four condition indices for four of the most common exotic species in the Estany d'Ivars i Vila-sana, a restored shallow lake in NE Iberian Peninsula. As part of a long-term monitoring program, this information could be useful for future management policies of these species and to evaluate and monitor the status of fish populations. Moreover, for the first time, we report information about the community of exotic fishes in a restored shallow lake as a result of a long-term monitoring and temporal variation of LWRs.

2. Results

Fish sampling led to the capture of 4619 individuals of nine different fish species. We only report the LWRs of pikeperch, roach, and common carp, since all other species were caught in low numbers (less than 100 individuals). Although only 21 individuals of bleak were captured, the LWR of this species was analyzed because of the interest in it as a common exotic species and the lack of data for lentic-introduced populations for this species. Furthermore, a new maximum total weight record was detected for bleak.

In total, 4557 fishes belonging to four species corresponding to two families (Cyprinidae and Percidae) were analyzed. All LWRs were highly significant ($p < 0.001$) and had a high coefficient of determination ($r^2 > 0.96$) (Table 1). In the four cases, the growth type was allometric (positive or negative), according to the confidence interval (b $CI_{95\%}$) (Table 1). Factor condition was calculated by using the four indexes for the four species (Table 2).

Analyses of covariances (ANCOVAs) revealed there were no significant annual differences in regression slopes for common carp ($F_{1, 405} = 0.094$, $p = 0.759$) or roach ($F_{1, 179} = 2.366$, $p = 0.126$) but significant differences for pikeperch ($F_{1, 3937} = 110.50$, $p < 0.001$). However, as expected, there were significant differences between the slopes for spring and summer fish (common carp: $F_{2, 405} = 5.042$, $p = 0.0069$; roach: $F_{1, 179} = 9.307$, $p = 0.003$; pikeperch: $F_{1, 3937} = 47.086$, $p < 0.001$) (Figure 1). Young-of-the-year (YOY) individuals were removed from analyses because they are not expected to be fully affected by environmental conditions. In consequence, after removing YOY individuals, the ANCOVA results did not change meaningfully so that we could obtain significant annual differences for pikeperch (ANCOVA common carp: $F_{1, 376} = 0.745$, $p = 0.389$; roach: $F_{1, 136} = 0.752$, $p = 0.387$; pikeperch: $F_{1, 741} = 10.966$, $p = 0.001$).

In most of our cases, condition-factor data did not fit to normal distribution ($p < 0.001$), and they did not show homogeneity of variances ($p < 0.001$), so Welch's tests were used to analyzed seasonal and annual differences on condition factors. In all cases, significant differences were detected ($p < 0.001$), so there are significant seasonal and annual differences. According to the *post hoc* test, condition factor was significantly worse at the end of the sampling period and in autumn. However, roach did not show seasonal differences.

Table 1. Descriptive statistics and estimated parameters of length–weight relationships (LWR: W = a L^b) for four fish species from the Estany d'Ivars i Vila-sana shallow lake, Northeastern Spain.

Species	Common Name	n [1]	FL [2] Range (cm)		Weight Range (g)		a [7]	95% CI a [8]	b [9]	95% CI b [10]	r^2 [11]	*p*-Value
			min [3]	max [4]	min [5]	max [6]						
Alburnus alburnus (Linnaeus, 1758)	Bleak	21	10.7	17.6	12.0	74.1 [12]	2.01×10^{-6}	5.15×10^{-7} to 7.80×10^{-6}	3.360	3.090 to 3.630	0.969	< 0.001
Cyprinus carpio Linnaeus, 1758	Common carp	409	6.5	66.4	6.1	4608	3.71×10^{-5}	3.13×10^{-5} to 4.37×10^{-5}	2.889	2.859 to 2.919	0.987	< 0.001
Rutilus rutilus (Linnaeus, 1758)	Roach	185	6.5	35.4	3.7	841	6.01×10^{-6}	4.92×10^{-6} to 7.34×10^{-6}	3.188	3.149 to 3.227	0.993	< 0.001
Sander lucioperca (Linnaeus, 1758)	Pikeperch	3942	4.0	73.8	0.5	3800	9.17×10^{-6}	8.78×10^{-6} to 9.59×10^{-6}	2.988	2.978 to 2.998	0.988	< 0.001

[1] Sample size; [2] fork length; [3] minimum fork length (cm); [4] maximum fork length (cm); [5] minimum total weight (g); [6] maximum total weight (g); [7] *a* parameter of the equation; [8] 95% confidence interval of a parameter; [9] *b* parameter of the equation; [10] 95% confidence interval of *b* parameter; [11] coefficient of determination; [12] new maximum total weight record not yet reported in the literature.

Table 2. Condition factors for each species. Fulton's condition factor (K_i), a modification of K_i (K_m), L–W relationship residuals (LWresid), and LeCren's relative condition factor (K_n). In all cases: median value ± standard error. LWresid median was calculated by using absolute values.

Species	K_i	K_m	LWresid	K_n
Bleak	1.212 ± 0.026	0.199 ± 0.004	0.024 ± 0.005	0.988 ± 0.019
Common carp	2.015 ± 0.017	3.697 ± 0.030	0.034 ± 0.002	1.001 ± 0.008
Roach	1.560 ± 0.016	0.600 ± 0.005	0.034 ± 0.002	1.000 ± 0.008
Pikeperch	0.871 ± 0.002	0.919 ± 0.002	0.036 ± 0.001	1.002 ± 0.003

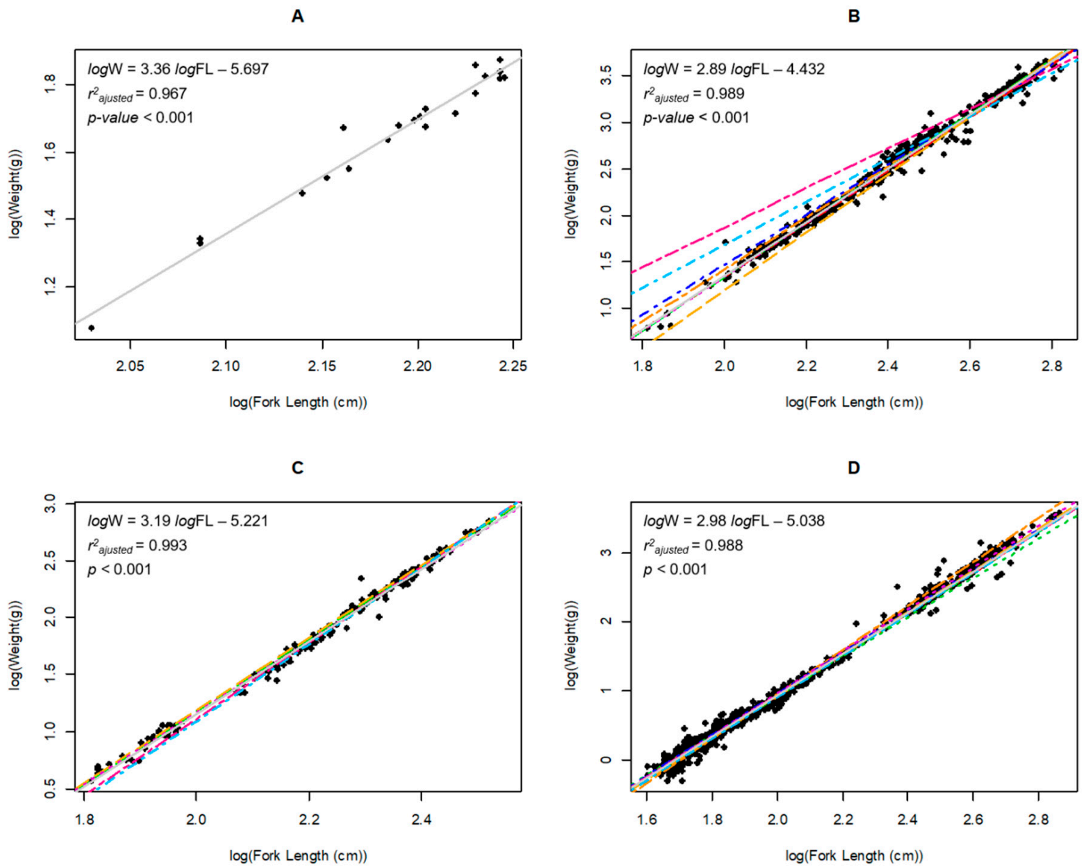

Figure 1. Length–weight relationships (LWR) for (**A**) *Alburnus alburnus* (Linnaeus, 1758), (**B**) *Cyprinus carpio* Linnaeus, 1758, (**C**) *Rutilus rutilus* (Linnaeus, 1758), and (**D**) *Sander lucioperca* (Linnaeus, 1758). In all graphs, the solid gray line is total LWR or regression lines. Dashed lines are annual LWRs for the eight years (2008 in dark-orange two-dashed line; 2009 in lime-green dotted line; 2010 in red dashed line; 2011 in blue dot-dashed line; 2012 in green long dashed line; 2013 in deep-pink two-dashed line; 2014 in goldenrod long-dashed line; 2015 in magenta dotted line; and 2016 in sky-blue dot-dashed line).

3. Discussion

This study should help facilitate fishery biologists to derive weight estimates for un–weighed but measured fish and assist them in estimating the biomass of captured fish species. Moreover, our results could help to evaluate the variation of exotic fish communities and the effects of control programs and management policies on similar communities and ecosystems.

We consider our results to be adequate estimations of LWRs for all species, since a minimum of 100 organisms were used to estimate these parameters; this number is considered an adequate sample size [9], except in the case of bleak, for which the results of might be considered with caution. Moreover, the b values in all cases fell within the expected range of $2.5 < b < 3.5$ [1] (b ranged from 2.889 to 3.360) (Table 1). Our results were compared with the FishBase database (https://www.fishbase.se/search.php) as of September 2019 [10]. In all cases, b varied in the range of b values for native populations (bleak: 2.700–3.430; common carp: 2.267–3.567; roach: 2.775–3.610; and pikeperch: 2.980–3.435) [10], and regression parameters a and b for these four species were within the range of Bayesian LWR predictions [3,10].

Conceptually, our results can be considered to be mean annual values for the species in our study, because fish samples were obtained during spring/summer and autumn, throughout the sampling period (2008–2016). As a consequence, these results are neither representative of a particular season nor a measure of seasonal growth.

Fish of a large range of lengths were caught with multi-mesh gillnets, obtaining a representative sample of all ages (Table 1). Still, it must be taken into consideration that the equations should be used with caution outside of the indicated length ranges.

According to FishBase [10], a bleak individual captured in 2008 provided new global maxima for total weight (74.1 g; Table 1). This new record might be considered with caution, because it could be registered within an optimal habitat for this alien species, from an ecosystem without significant predation pressures. In fact, this record belongs to a single individual captured in 2008, and only one more bleak was captured two years later. This record and the changes in fish community composition from the Estany d'Ivars i Vila-sana can be explained by a modification of physicochemical characteristics to suboptimal conditions characterized by seasonal variations with increment of water temperature (up to 28.5 °C in summer at 0.5–1 m depth) and a reduction of dissolved oxygen (down to 1.05 $mg \cdot L^{-1}$ and 11.5% oxygen saturation at 1.5 m depth) in spring and early summer and a gradual but constant increment of predators such as pikeperch (authors, unpublished results).

Our results showed significant changes in LWR between early summer and autumn (early summer's slope < autumn's slope). These results are explained by the differences in food availability and environmental conditions. In fact, for pikeperch, roach, and common perch, b values were higher in autumn than in early summer. This is explained by LWR values that were determined by the availability of trophic resources and the feeding period during the summer season. In fact, factor condition analyses confirmed these differences between seasons and the consequences of winter food restrictions.

Apparently, environmental changes do not have a clear effect on fish conditions, since no significant annual differences were found in LWR slopes, according to the ANCOVA results ($p > 0.05$ for common carp and roach), but in all cases, their condition factors showed a significant reduction in 2014 and 2016. For pikeperch, the most numerous species in the lake, significant annual differences ($p < 0.05$) were found, and the lowest slopes happened in 2010 and 2011. During these years, a decrease in pikeperch catch-per-unit-effort (CPUE) and biomass-per-unit-effort (BPUE) was also detected (unpublished data). As it was expected, due to the fact that condition factors are highly correlated with LWR (except LWresid), a similar pattern was detecting by analyzing differences in factor condition indexes, showing, in general terms, a better condition in early stages (2008–2010) and worse conditions at the end of this study (2014 and 2016). This populational dynamic follows bust-and-boom populational dynamics [11,12] widely detected in other ichthyological communities of alien species. Although we did not obtain significant results for common carp, in 2010 and 2011, low slopes were detected, but the lowest slope took place in 2013. However, in this case, the lowest slopes were related to the highest CPUE and BPUE values. This is because captures in 2013 were limited to adults, the size range of which was from 440 to 664 mm. In fact, no juveniles were captured in 2013. In global terms, these results might be explained by a complex junction of unknown variations on lacustrine physicochemical conditions, as well as ecosystem and trophic interaction between species. After removing YOY individuals, ANCOVAs were repeated for all the species obtaining similar results.

According to the obtained results, this study provides a useful tool for the stakeholders involved in the management of the Estany d'Ivars i Vila-sana, novel information about the community of exotic fish in a restored shallow lake, and a contribution to the available LWRs for these exotic species, within the context of a Mediterranean restored shallow lake during a long-term period. These results encompass the effects and consequences of the ecological processes within an ecosystem where the ichthyologic community is being established and is evolving in concordance with the ecosystem conditions.

4. Materials and Methods

The Estany d'Ivars i Vila-sana is a shallow lake with an area of 131.3 ha, and mean and maximum depths of 1.9 and 3.8 m, respectively, in which the water temperature ranges from 3 to 5 °C in winter, and from 26 °C to 28 °C in summer [13]. We sampled fish twice a year (spring/early summer and autumn) between 2008 and 2016 by using between three and five multi-mesh nylon gillnets that were 48 × 1.5 m in length and height, respectively, according to European standardized methods [14]. Each gillnet consisted of a series of 16 panels (3 m width and 1.5 m height) of different mesh sizes, ranging from 6.25 to 135.00 mm bar length. All nets were set up simultaneously, in the late afternoon, at 0–2 m depth, and lifted the next morning, averaging a soak time of 12 h. All captured fish specimens were weighed to the nearest gram and identified at species level, and their FL was measured to the nearest millimeter. Captured specimens were weighed and measured immediately after being released from the gillnets at lakeside.

Nine different fish species were detected in the lake during the last nine years. Seven of those species are exotic in the Iberian Peninsula: bleak, *Alburnus alburnus* (Linnaeus, 1758); *Carassius* sp. (Linnaeus, 1758); common carp, *Cyprinus carpio* Linnaeus, 1758; roach, *Rutilus rutilus* (Linnaeus, 1758); pikeperch, *Sander lucioperca* (Linnaeus, 1758); rudd, *Scardinius erythrophthalmus* (Linnaeus, 1758); and Iberian gudgeon, *Gobio lozanoi* Doadrio and Madeira, 2004, which is allochthonous in the Ebro basin. Only two native species were caught: ebro barbel, *Luciobarbus graellsii* (Steindachner, 1866) and catalan chub, *Squalius laietanus* Doadrio, Kottelat, and Sostoa 2007.

The LWRs of the captured fish species were established by using a linear regression analysis based on the least squares method [15]. LWRs are usually described through a potential function ($W = a{\cdot}L^b$) [5,16] that becomes linear after a logarithmic transformation of length–weight data. We thus represented LWRs as follows:

$$\log_{10} W = \log_{10} a + b \log_{10} L, \quad (1)$$

where W is weight (g) and L is fork length (cm). Parameter a is the intercept, and parameter b (slope) indicates the growth type (when $b = 3$, then isometric growth; if $b \neq 3$, then allometric growth) [1,5,16]. Parameters a and b were determined via least-squares linear regression [15]. Before performing the regression analysis, we inspected length–weight and log–log plots, to detect and remove outliers [1]. The 95% confidence interval for b (95% CI) was computed by using the following equation:

$$\mathrm{CI} = b \pm (1.96 \times SE), \quad (2)$$

where SE is the standard error of b, which was calculated to determine if the hypothetical value of isometry fell within these limits [1]. The same process was used for a. Additionally, the determination coefficient (adjusted r^2) was estimated.

2.1. Fish Condition

Fish condition has been calculated by using four different condition metrics. First, Fulton's condition factor (K_i) that assumes isometric growth, son b is 3, where the shape of the fish does not change with increasing length [17], and it was calculated for an individual fish by using the following formula [18]:

$$K_i = W_i/L_i^3 \times \text{constant}, \quad (3)$$

where L_i and W_i are the observed length (fork length in mm) and (weight in g) for the ith fish, and the constant is a scaling factor equal to 100,000 if metric units. However, most of populations of fish do not exhibit isometric growth [1], so K_i depends on the length of the fish [17] and is specific for a population under determined conditions. Thus, comparisons of Fulton's condition factor are restricted to fish of similar lengths within the population [17–19]. Fulton's condition factor is seldom used in modern studies because of this limitation.

Then, a modification of K_i was calculated (K_m) according to the following formula [20,21] and using the exponent b derived from the length–weight relationship for each species (Table 1), described by formula:

$$K_m = W_i/L_i^b \times 100.000, \quad (4)$$

We have also used residuals from the weight–length relationship to measure fish conditions [18,19], and they were calculated as the difference between the observed log weight and the expected log weight, according to (log) weight–length regression.

$$\text{Residual} = L_{i\ obs} - L_{i\ esp}, \quad (5)$$

The LeCren's relative condition factor (Kn_i) [5] for the *i*th fish was calculated as follows [18]:

$$Kn_i = W_i/W_{pred}, \quad (6)$$

where W_i is the observed weight (in g) and W_{pred} is the predicted mean weight, given the fish's observed length for the population of fish under investigation [22]. In consequence, the value of Kn_i does not depend on length within the population being investigated [23].

2.2. Statistics

To analyze the variation of the LWR for each species, we conducted ANCOVAs, looking for significant differences in slopes by comparing the slopes of annual and seasonal LWRs. Thus, year or season was included as a factor, log-transformed fork length (logFL) as a covariate, and log-transformed weight (logW) as a dependent variable in theses ANCOVAs. Morphology underlies interactions with other organisms, conspecific individuals, and the environment. However, as YOY individuals (0+ or age 0 individuals) are not expected to have total morphological expression of environmental factors, but, at the same time, due to the huge number of captured individuals, they were removed, to avoid the bias they can cause, and the analyses of covariance were repeated. ANCOVA could not be performed for bleak, because only 21 individuals were captured (Table 1)—20 of them in 2008.

Analysis of variance and Tukey's *post hoc* tests were used to analyze annual and seasonal differences on condition factor. All data were tested for homogeneity of variance by the Levene test and for normality by the Shapiro test. If conditions for ANOVA were not fulfilled, the Welch's test was used.

Finally, the standard lengths and total weights observed were compared with the information provided by FishBase [10]. All statistical analyses were carried out by using R version 3.5.1 [24], except when specified otherwise.

Sampling events have been authorized by the Department of Territory and Sustainability of the Government of Catalonia. Annual special authorizations for scientific captures are available, if required. The approval of an ethics committee is not compulsory in Spain.

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