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RESEARCH NOTE

Length-weight relationships for 25 kelp forest-associated fishes of northern and central Chile

Relaciones de longitud-peso para 25 peces costeros asociados a macroalgas pardas del centro y norte de Chile

Alejandro Pérez-Matus[1], Sergio A. Carrasco[1] and Andrés Ospina-Alvarez[2]

[1]Subtidal Ecology Laboratory & Center for Marine Conservation, Estación Costera de Investigaciones Marinas, Pontificia Universidad Católica de Chile, Casilla 114-D, Santiago, Chile. aperez@bio.puc.cl
[2]Centro de Conservación Marina & Departamento de Ecología, Facultad de Ciencias Biológicas, Pontificia Universidad Católica de Chile, Casilla 114-D, Santiago, Chile

Abstract.- The present study reports length-weight relationships for 25 species of reef fishes associated with large brown macroalgae (*i.e., Lessonia trabeculata* and *Macrocystis pyrifera*) from the northern and central rocky coast of Chile (Southeast Pacific Coast; 18°-33°S). Weight scaled to length with an average power of 2.85, close to the expected value of 3, meaning that the relationship between length and weight is close to an isometric growth. No latitudinal (*i.e.,* spatial) and temporal variations were observed on the growth coefficient of the fish species studied.

Key words: Rocky reefs, fish assemblages, distribution, allometric growth

INTRODUCTION

Size has a major impact on most features of fish biology. It is biologically more important than age, and can be constrained by ecological, behavioral and physiological factors (Wootton 1999). The understanding of size variation among species may have implications for diverse fields of fishery science, population and community dynamics (Santos *et al*. 2002). Length-weight relationships can be used to convert field-based estimates of lengths into weights, which can in turn be used to estimate growth rates of individuals (Taylor & Willis 1998) and biomasses of population and communities (Mora *et al*. 2011). When evaluated overtime, length and weight parameters can also be used to indicate changes in growth strategies associated with environmental disturbances, such as climate change, ocean acidification, disease, starvation, exploitation, among others (Csirke 1980).

Chilean temperate rocky reefs are dominated by large brown macroalgae (*i.e.*, *Lessonia trabeculata* and *Macrocystis pyrifera*), with these canopy-forming species providing habitat for a number of fish species (Fig. 1) (Pérez-Matus *et al*. 2007, 2012). Nonetheless, basic biological information on most of these fish species is yet absent or unpublished. We aimed to provide the first L-W reference for 25 fish species inhabiting shallow subtidal reefs in northern and central Chile.

MATERIALS AND METHODS

STUDY AREA AND SAMPLING

The data reported herein were collected at 7 different sites along the northern and central Chilean coast (18°-33°S; Fig. 1) during austral summer and spring 2004-2005 (Rio Seco, Caleta Constitución, Caleta Angosta and Lagunillas) and in spring 2012-2013 (Lagunillas, Zapallar, and Punta de Tralca). Generally, sites were characterized as shallow subtidal rocky reefs (~15 m depth) dominated by the co-occurring large brown macroalgae *L. trabeculata* and *M. pyrifera*. Specimens were caught with different fishing gear such as gill nets (2.5 cm overture), spear gun (90 cm), hook and line and baited cages (60 x 80 cm and 60 cm height). All collections were performed during 10:00 to 16:00 h to minimize potential variability in the foraging behavior of the focal species. Most of the measurements of fish total length (L) and weight (W) were performed at fish's catch sites (see S1 supplementary data in Pérez-Matus *et al*. 2014). Total length was measured with an ichthyometer (*i.e.,* 50 cm PVC tubes with a 5 cm aperture on top and a measuring tape on inner bottom to contain the fish during the measuring process) to the nearest 1 mm and fresh weights were measured using analytical balances with an accuracy of 1 g.

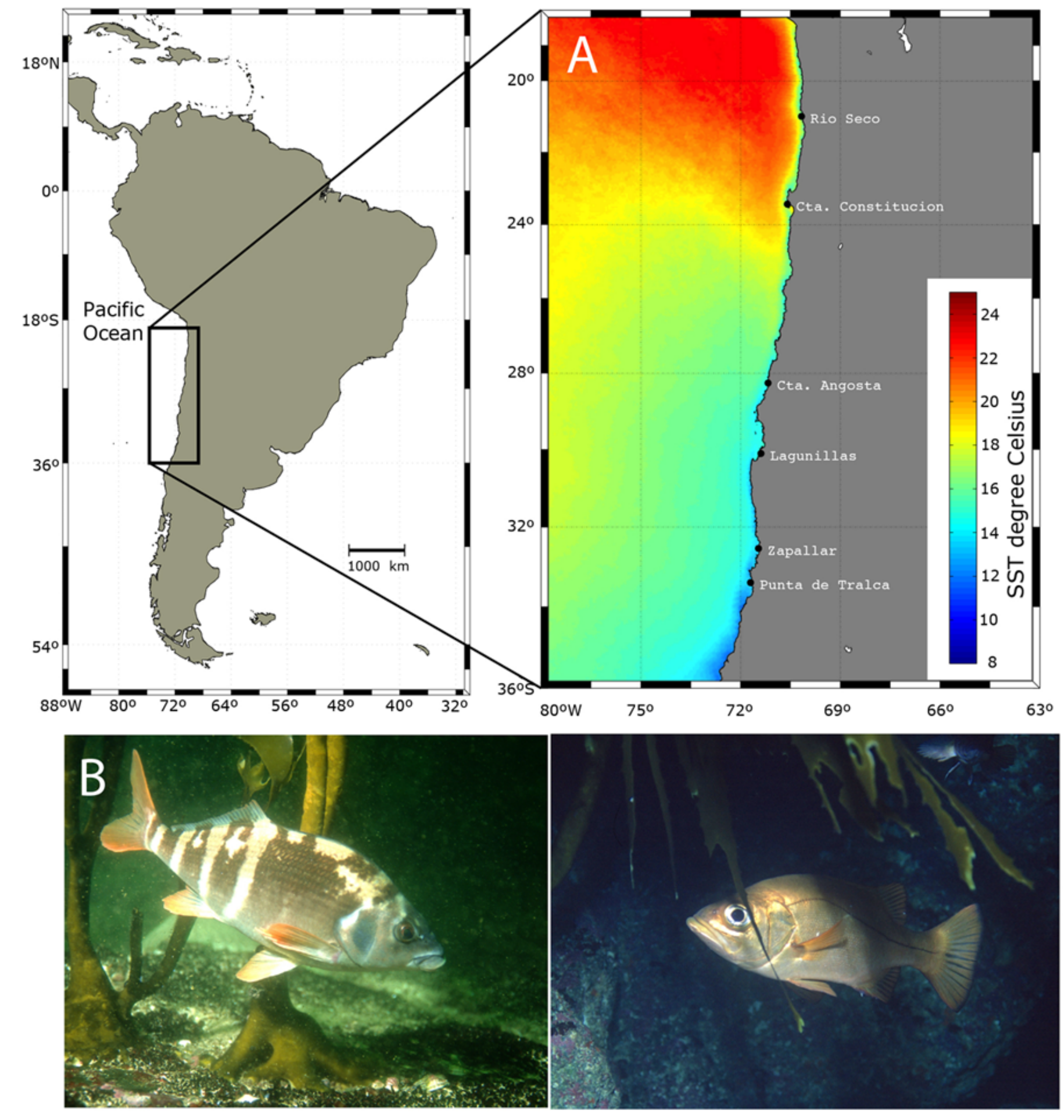

Figure 1. Map of the sampling and collection sites along with: A) interannual average night sea surface temperature from 5th July 2002 to 1st August 2013 which represent the temporal framework of the species collections (see methods for details) for each site. Nighttime Sea Surface Temperature (NSTT) data was acquired and extracted from the moderate resolution imaging spectroradiometer 'MODIS AQUA L3' satellite data (incorporating standard atmospheric corrections)[1] with a resolution of 1.2 km at high temporal frequency validated. B) pictures of representative species collected such as *Cheilodactylus variegatus* (bilagay) and *Hemilutjanus macrophthalmos* (apañao) (photo credit: A. Pérez-Matus) / Mapa de los sitios de muestreo y colecta de peces con: A) Promedio de la temperatura superficial del mar, registro nocturno, entre el 5 de julio de 2002 al 1 de agosto de 2013 representando la escala temporal de la colecta de especies (ver métodos para más detalles). La temperatura superficial del mar fue extraída de una imagen satelital de resolución moderada (1,2 km) del espectroradiómetro 'MODIS AQUA L3' (incorporando correcciones atmosféricas)[1] y validada en alta frecuencia temporal. B) Fotografías de especies de peces representativas tales como *Cheilodactylus variegatus* (bilagay) y *Hemilutjanus macrophthalmos* (apañao) (créditos: A. Pérez-Matus)

[1]<ftp://podaac.jpl.nasa.gov>, thermal IR SST, 4 km and 0.1°C resolution from MODIS databases

Data analysis

We used Huxley's (1932) power function, $W = \alpha L^b$, where L represents the total or fork length (cm) size, W the total weight (g), α the intercept (initial growth coefficient or condition factor) and b the slope (growth coefficient, *i.e.*, fish relative growth rate), to express the scaling relationship of length-weight for the 25 fish species included in the model below. Length-weight allometry was quantified by deriving exponent α by regressing the natural logarithm of the length of each species against the natural logarithm of body mass and obtaining the slope.

Slopes were calculated using regression ordinary least squares (OLS) and the association degree between L and W was calculated by the determination coefficient r^2. Additionally, 95% confidence limits of α intercept and b slope and the statistical significance level of r^2 were estimated. All data management and analysis were performed using the R statistical software, version 3.0.0 (R Development Core Team 2012) with R base packages (see S2 supplementary data in Pérez-Matus *et al*. 2014). Regression ordinary least squares and testing for the different species regressions were computed using package 'smatr', version 3.4 (Warton et al. 2012).

Equally, we tested the relationship of L-W discriminated by study sites to test if growth coefficient changed due to geographical (*i.e.*, latitudinal) range. We spatially pooled the information since no statistical differences among slopes were detected among sites ($P > 0.05$), hence years (see above).

Results and discussion

A total of 760 individuals from 25 different species were collected in the present study, with length-weight equations applying to most teleost species commonly found on shallow subtidal reefs in northern and central Chile (Angel & Ojeda 2001, Pérez-Matus *et al.* 2007). L-W relationships, growth coefficients, and length-weight equations, along with different descriptive statistics for all species collected are presented in Table 1. Values of growth coefficient (b) ranged from 1.44 to 3.75, with a mean of 2.85 ± 0.48 (SD). The comparison between obtained values of t-test and the respective tabled critical values allowed for the determination of the b-values statistical significance, and their inclusion in the isometric range (b = 3) or allometric ranges (negative allometry: $b < 3$ or positive allometry: $b > 3$). The value of 2.85 was less than the rate of isometric growth of 3, meaning that on average, fishes associated to large brown macroalgae have a negative allometric growth; hence size (*i.e.*, growth) was not proportional to weight. This differed to reef fishes from other temperate kelp forest systems as New Zealand, where growth has been shown to be nearly isometric (*i.e.*, fish structure remains constant with growth; Taylor & Willis 1998).

Slopes of the length-weight regressions were not significant for the following species: *Labrisomus philippii*, *Paralichthys adspersus*, *Nexilosus latifrons*, *Sebastes oculatus* and *Helcogrammoides chilensis*, suggesting that these 2 variables were dependent to one another. In other words, data for these fish species did not spanned a reasonable size range to estimate α and *b* parameters (Table 1). Despite differences in cumulative sea surface temperature (see Fig. 1), the L-W relationship was constant. This is consistent with results from other systems such as the north Atlantic (Morato *et al.* 2001), suggesting that temperature primarily affects fish by altering their growth rates, not their weight at a given length.

Sexual dimorphism in length-weight relationships could occur in *Semicossyphus darwini* and *Graus nigra*, because of sequential hermaphroditism in the former and energy allocation hypothesis in the latter. We did not have sufficient males for *S. darwini* and no females for *G. nigra*. Nonetheless, Flores & Smith (2010) reported a slight sexual dimorphism in L-W relationship in *G. nigra*, with males having an isometric growth and females a negative allometric growth. Our estimates were similar to those reported by Flores & Smith (2010) for *G. nigra*, confirming the low variation in growth estimates among the species at different sites. Beside that study, no other source of information regarding length-weight relationships existed for kelp-forest associated fishes of northern-central Chile. This is relevant considering the fishing pressure that many of these populations are currently experiencing (Godoy *et al.* 2010).

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Table 1. Descriptive statistics and L-W relationship parameters for 25 kelp forest-associated fishes of the South East Pacific Coast (Chile). N: sample size; L: total length (cm); W: fresh weight (g); SD: standard deviation; SE: standard error; CI: Confidence interval; a: intercept; b: slope. After the scientific name, the common name is indicated in parentheses / Estadísticos descriptivos y relación de los parámetros de L-P para 25 especies de peces asociados a macroalgas de la costa Este del Pacifico Sur (Chile). N: Numero de muestras; L: longitud total (cm); W: peso fresco (g); SD: desviación estándar; SE: error estándar; CI: Coeficientes de intervalo; a: intercepto; b: pendiente

Family/Species (common name)	N	L, mean ± SD (range)	W, mean ± SD (range)	W-L equation	Determination coefficient (r^2)	SE of b[a] (95% CI of b)	Relationship (t-test)
Aplodactylidae							
Aplodactylus punctatus (jerguilla)	126	32.4 ± 5.2 (8.7-43.5)	504.5 ± 221.0 (6.4-1400)	$W = 0.0108\ L^{3.067}$	0.92 ($P < 0.01$)	1.012 (2.906-3.228)	Isometric
Blenniidae							
Hypsoblennius sordidus (trombollito robusto)	16	6.1 ± 1 (5-8.6)	3.6 ± 1.8 (1.37-8)	$W = 0.0339\ L^{2.541}$	0.69 ($P < 0.01$)	1.032 (1.577-3.505)	(–)Allometry
Scartichthys viridis (borrachilla verde)	126	9.2 ± 2 (5.5-19)	9.9 ± 10.6 (2.07-92.9)	$W = 0.0191\ L^{2.736}$	0.86 ($P < 0.01$)	1.019 (2.541-2.932)	(–)Allometry
Carangidae							
Trachurus murphyi (jurel)	3	37.3 ± 3.2 (35.3-41)	466.7 ± 115.5 (400-600)	$W = 0.0213\ L^{2.757}$	0.99 ($P = 0.02$)	1.022 (1.590-3.925)	(–)Allometry
Centrolophidae							
Seriolella violacea (cojinova)	18	35.4 ± 12 (29.8-39)	447.4 ± 147.1 (275-700)	$W = 0.0014\ L^{3.578}$	0.90 ($P < 0.01$)	1.002 (2.949-4.209)	(+)Allometry
Cheilodactylidae							
Cheilodactylus variegatus (bilagay)	94	28.3 ± 3.8 (22.9-44)	406.7 ± 372.6 (170-2080)	$W = 0.0208\ L^{2.969}$	0.39 ($P < 0.01$)	1.023 (2.009-3.425)	(–)Allometry
Clinidae							
Myxodes viridis (doncellita)	3	5.4 ± 2.7 (2.6-8)	1.8 ± 1.5 (0.19-3.24)	$W = 0.0172\ L^{2.611}$	0.97 ($P = 0.11$)	1.017 (-3.218 - 8.442)	(–)Allometry
Haemulidae							
Anisotremus scapularis (sargo)	40	26.8 ± 3 (21.2-34.2)	420.5 ± 160.8 (200-1000)	$W = 0.0199\ L^{3.013}$	0.92 ($P < 0.01$)	1.022 (2.714-3.312)	Isometric
Isacia conceptionis (cabinza)	30	18.6 ± 12.9 (12.5-34.4)	255.4 ± 419.7 (19.8-700)	$W = 0.0091\ L^{3.095}$	0.80 ($P < 0.01$)	1.010 (2.501-3.690)	Isometric
Kyphosidae							
Girella laevifrons (baunco)	70	25.8 ± 4.1 (4-38.3)	349.7 ± 163.2 (1.2-1200)	$W = 0.0088\ L^{3.160}$	0.95 ($P < 0.01$)	1.010 (2.810-3.129)	Isometric
Graus nigra (vieja), male	6	45.4 ± 12.7 (29.2-64.6)	1880.8 ± 1557.1 (420-4860)	$W = 0.0123\ L^{3.160}$	0.98 ($P < 0.01$)	1.014 (2.557-3.763)	Isometric
Labridae							
Semicossyphus darwini (pejeperro) female/male	19	42.4 ± 10.7 (33.3-68)	1864.3 ± 1342.1 (540-5811)	$W = 0.0134\ L^{2.971}$	0.97 ($P < 0.01$)	1.015 (2.753-3.314)	(–)Allometry
Labrisomidae							
Labrisomus philippii (chalaco)	6	28.9 ± 3.7 (23.7-34.9)	365 ± 117.8 (200-480)	$W = 0.2094\ L^{2.208}$	0.61 ($P = 0.06$)	1.181 (-0.228-4.645)	(–)Allometry
Mugilidae							
Mugil cephalus (lisa)	9	36.3 ± 3.1 (32.5-41.6)	556.7 ± 131.8 (420-740)	$W = 0.0432\ L^{2.629}$	0.90 ($P < 0.01$)	1.043 (1.871-3.388)	(–)Allometry
Paralichthyidae							
Paralichthys adspersus (lenguado)	3	36.5 ± 1.7 (29.5-32.5)	594.5 ± 306.2 (240-400)	$W = 0.0006\ L^{3.7892}$	0.68 ($P = 0.38$)	1.001 (-28.897-36.475)	(+)Allometry
Pinguipedidae							
Pinguipes chilensis (rollizo)	22	36.7 ± 4.8 (25.3-51)	618.2 ± 288 (220-1750)	$W = 0.0346\ L^{2.703}$	0.90 ($P < 0.01$)	1.035 (2.274 - 3.132)	(–)Allometry
Pomacentridae							
Chromis crusma (castañeta)	8	16.8 ± 8 (3.1-23)	117 ± 74.6 (0.8-189)	$W = 0.0278\ L^{2.826}$	0.99 ($P < 0.01$)	1.029 (2.691-2.962)	(–)Allometry
Nexilosus latifrons (castañeta del norte)	4	32 ± 10.1 (20.6-23.2)	521.7 ± 345.9 (200-300)	$W = 0.0075\ L^{3.350}$	0.87 ($P = 0.07$)	1.009 (-0.622-7.324)	(+)Allometry
Sciaenidae							
Sciaena deliciosa (roncacho)	29	34.6 ± 3.2 (28-46.5)	858.1 ± 100.5 (400-800)	$W = 0.3219\ L^{1.452}$	0.55 ($P < 0.01$)	1.128 (0.932-1.973)	(–)Allometry
Sebastidae							
Sebastes oculatus (cascajo, cabrilla)	3	25 ± 4.4 (20-28)	226.7 ± 92.4 (120 - 280)	$W = 0.0448\ L^{2.636}$	0.99 ($P = 0.06$)	1.044 (-0.678-5.951)	(–)Allometry
Serranidae							
Acanthistius pictus (vieja tiuque)	9	36.6 ± 4.2 (27-41.6)	880 ± 329.5 (415-1410)	$W = 0.1038\ L^{2.497}$	0.55 ($P = 0.02$)	1.100 (0.476-4.517)	(–)Allometry
Hemilutjanus macrophthalmos (apañao)	19	30.6 ± 3.9 (26.5-36.5)	453.2 ± 165 (200-750)	$W = 0.0269\ L^{2.828}$	0.89 ($P < 0.01$)	1.028 (2.318-3.339)	(–)Allometry
Paralabrax humeralis (cabrilla)	22	33.9 ± 15.1 (28.5-47.5)	498.4 ± 202.1 (280-1250)	$W = 0.1824\ L^{2.234}$	0.80 ($P < 0.01$)	1.158 (1.714-2.755)	(–)Allometry
Tripterygiidae							
Helcogrammoides chilensis (trombollito tres aletas)	3	7.3 ± 3.7 (5-11.3)	6.9 ± 9 (2-17.36)	$W = 0.0034\ L^{2.969}$	0.99 ($P = 0.06$)	1.004 (-0.559-6.498)	(–)Allometry
Helcogrammoides cunninghami (trombollito tres aletas)	72	4.2 ± 0.7 (2.8-6.2)	0.7 ± 0.5 (0.14-2.5)	$W = 0.0034\ L^{3.597}$	0.93 ($P = 0.01$)	1.004 (3.356-3.840)	(+)Allometry

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