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Every Fish Counts: Challenging Length–Weight Relationship Bias in Discards

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Abstract: Bycatch is a significant issue in global fisheries and understanding the length–weight relationships (LWR) of fish species can provide valuable insights for stock assessment and management efforts. In this study, we estimated the LWR of 74 fish species in trawl fleet discards from the Gulf of Cadiz, including 24 species for which LWR data had not been previously reported in this region. LWR was calculated from the formula $W = aL^b$ where parameter a is the intercept of the equation, related to body shape, and parameter b is the slope, which indicates the type of growth of the species. A total of 20,007 individuals from 40 families were measured and weighed. The most abundant species were *Engraulis encrasicolus*, *Trachurus trachurus*, *Serranus hepatus*, *Sardina pilchardus*, *Capros aper*, and *Diplodus bellottii*, and the Sparidae family was the most represented with ten species. The parameter b, which represents the type of growth, ranged from 2.1607 to 3.7040. A positive allometric growth trend was observed in 64% of the species. The inclusion of individuals with a low sample size proved useful, particularly for first reports in a new study area. However, caution should be taken when using these data, as the estimates of the length–weight relationship for these species may be less precise. Further studies with larger sample sizes are needed to confirm the results and improve the accuracy of the estimates. Overall, our findings contribute to the understanding of the LWR of fish species in the Gulf of Cadiz, informing future research and management efforts in the region.

Keywords: fisheries; body length; fish biometrics; growth; professional fleet; measurements

Key Contribution: This work has reported for the first time in the Gulf of Cadiz, the length–weight relationships of 24 species including the length–weight relationship of the non-native species *Cynoscion nebulosus*. After analysis of the low sample size data, the bias from these data can be assumed for a first comparison of length–weight relationships, concluding that species from discards are useful in length–weight relationships studies.

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1. Introduction

Bycatches are one of the main current global problems for fisheries [1,2]. Discards are specimens of both species with little or no commercial interest and commercial species that cannot be marketed due to deterioration or not meeting the legal size, which are returned, alive or dead, to the sea and are not counted among the catch [3,4]. Discarding is a particularly common practice in trawl fisheries [3,5,6]. These discards produce a series of ecological and economic consequences, such as endangering the sustainability of marine organism populations or wasting large amounts of natural resources [1,3,4,6,7].

Discards in fisheries may be biased by the way in which catches are selected. Bias can occur when the data used to fit the model do not adequately represent the underlying population. This can occur when non-target species are selectively discarded because of their size, age, or shape, which can lead to underestimates of the amount of unwanted catch, affecting the precision of estimates and having implications for fisheries management [8]. In addition, it is important to keep in mind that results obtained from a biased model may not be generalizable to other populations or contexts [9].

Knowing length–weight relationships (LWR) is important because it allows for numerical estimates of fish condition, comparisons between living conditions in different regions for the same species, biomass calculations from length data, or transformations of length growth equations to weight growth, all of which have different applications in stock assessment and management models [10–21]. LWR can also be used to estimate the amount of discard of a given species through its size distribution [22,23].

Understanding the LWR of fish species is essential for sustainable fisheries management and conservation, as it enables the estimation of fish species distribution, their condition, and morphological comparison [17,24]. Incorporating LWR in fisheries management can help address discard issues and improve sustainability:

(1) Informing the development of size-based regulations: length–weight relationships can be used to determine the size at which a fish species reaches maturity [17]. This information can inform the establishment of minimum landing sizes, helping to protect juveniles and ensuring that fish can reproduce before being harvested [25].
(2) Assessing the impact of fishing practices: comparing the length–weight relationships of discarded and retained fish can reveal the effects of fishing practices on size distribution and species composition [26]. This knowledge can be used to modify fishing gear, practices, or policies to minimize the capture of unwanted species or sizes, reducing discards and promoting sustainability.
(3) Monitoring ecosystem health: regular analysis of length–weight relationships can provide insights into the overall health of an ecosystem [27]. Shifts in these relationships may signal changes in the abundance, growth, or reproductive success of a species, which could be linked to the impacts of fishing or other anthropogenic pressures [28]. Tracking these changes can inform adaptive management strategies to maintain ecosystem health and ensure the long-term sustainability of fisheries [29].

Sustainable fisheries management is crucial for maintaining the health and productivity of marine ecosystems, ensuring food security, and supporting the livelihoods of coastal communities [30,31].

In the Gulf of Cadiz and Southern Portugal several LWR works have been carried out for different species [23,32–38], with some more focused on species of commercial interest [39–41].

The present study seeks to address the gap in knowledge regarding the LWRs of discarded fish species in the Gulf of Cadiz, with a focus on species not previously studied in this area. This research aims to provide valuable insights into the biology and ecology of these species, which can ultimately inform management, conservation, and recovery plans for exploited species in the region. The low-sampled LWRs have been compared with results from adjacent areas in order to assess their utility and applicability to other study areas.

2. Materials and Methods

The data analyzed were collected through the ECOFISH, ECOFISH2, ECOFISH+, and ECOFISH 4.0. projects, carried out by the University of Cadiz, during the period 2019–2022. The main objective was to analyze and characterize the composition and structure of the discard associated with the trawl fishery in the Gulf of Cadiz (Figure 1). To this end, samplings were carried out with the professional fleet of Sanlúcar de Barrameda and El Puerto de Santa María. The Gulf of Cadiz trawl fleet uses trawls nets with a mesh size of 55 mm. In each haul, an average of 11 kg of discard were collected randomly. Discards in this fleet are caused mainly because the species are not of commercial interest, because they do not have legal size, or because they are species subject to TACs (total allowable catches) in the Gulf of Cadiz and, in addition, because they cannot be caught with this gear, such as anchovy (*Engraulis encrasicolus*, Linnaeus 1758). A total of 90 hauls were analyzed. The depth range was between 15–549 m. Specimens were identified to species level following the descriptions of Whitehead et al. [42] and Lloris [43]. Following Froese [17], rare species with low sample size values were taken into account, despite their low occurrence.

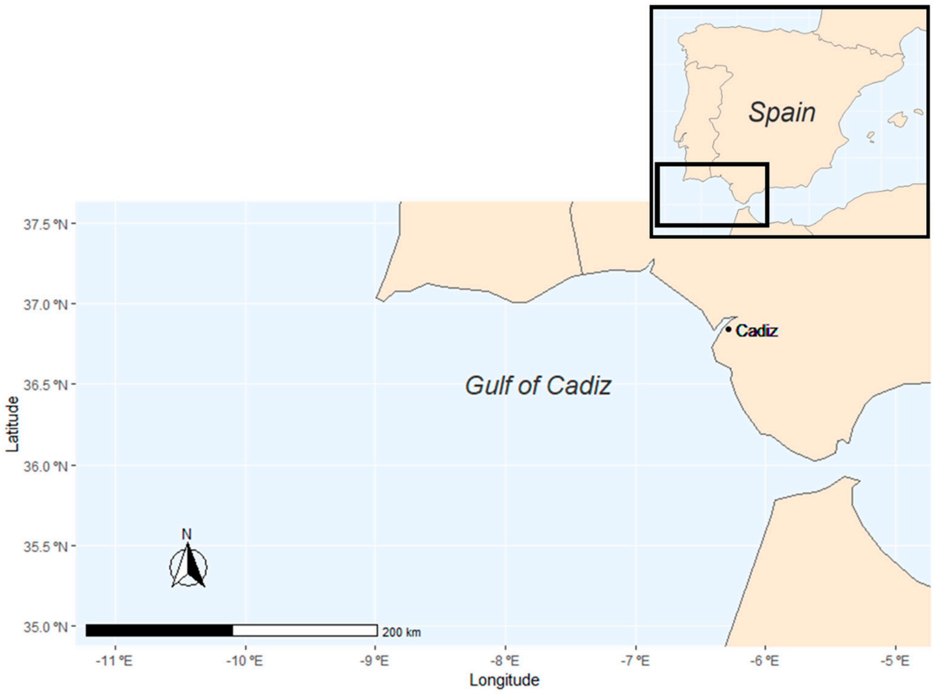

Figure 1. Map of the Gulf of Cadiz (SW Spain).

All specimens were measured for total length (TL) and total weight (TW) to the nearest ±0.1 cm and ±0.01 g, respectively.

LWRs were calculated following the equation $W = aL^b$ [44,45], where W is the total weight of the fish and L is the total length. The parameters of LWR were estimated by linear regression, according to the least squares method: $\ln(W) = \ln(a) + b\ln(L)$. Where a is the intercept of the regression curve, related to the body shape, and b is the slope, related to the type of growth, with $b < 3$ being a tendency to negative allometric growth (having a greater growth in length than in weight), $b = 3$ an isometric growth and $b > 3$ a tendency to positive allometric growth (growing more in weight than in length) [17]. From this equation, the coefficient of determination (R^2) was calculated with a confidence level of 95%. A plot of *log a* vs. *b* was used to detect outliers in LWR within species [17,46]. The residuals vs. leverage plot was used to identify those potential outliers through Cook's distance comparisons [47].

Validity of the LWRs of the species with a low sample size ($n < 12$) was checked by comparing the parameters of the relationships with the studies saved in FishBase database [24] and with similar studies carried out in areas adjacent to the study area (southern coast of Portugal). Thus, the growth type of each species was compared and the differences between parameters a and b were interpreted taking into account the length ranges sampled and the number of specimens.

All statistical analyses were carried out with R version 4.2.1. and RStudio version 1.1.463 [48,49].

3. Results and Discussion

In this study, 20,007 individuals of 74 different species (40 families) were analyzed. The most abundant species were anchovy *E. encrasicolus*, Atlantic horse mackerel *Trachurus*

trachurus (Linnaeus, 1758), brown comber *Serranus hepatus* (Linnaeus, 1758), European sardine *Sardina pilchardus* (Walbaum, 1792), boarfish *Capros aper* (Linnaeus, 1758), and Senegal seabream *Diplodus bellottii* (Steindachner, 1882). The most represented family was Sparidae with ten species. In this work, the LWR of 24 species is cited for the first time in the Gulf of Cadiz, highlighting Spotted weakfish *Cynoscion nebulosus* (Cuvier, 1830), a non-native species in the area [50,51].

The species are shown in Table 1, where the sample size, the minimum, mean, and maximum values of TL (cm) and TW (g), as well as the parameters *a* and *b* of the LWR, their 95% confidence intervals, the coefficient of determination (R^2), and *p*-value are indicated.

Linear regressions were significant for all species ($p < 0.05$). The R^2 ranged from 0.707, for Transparent goby *Aphia minuta* (Risso, 1810), to 0.996, for Rendezvous fish *Polymetme corythaeola* (Alcock, 1898) and comber *Serranus cabrilla* (Linnaeus, 1758). The variance explained was greater than 95% for 84% of the species. Parameter *a* had values between 0.005, for European conger *Conger conger* (Linnaeus, 1758), and 0.0454, for Wedge sole *Dicologlossa cuneata* (Moreau, 1881). Parameter *b* ranged from 2.161, for Red bandfish *Cepola macrophthalma* (Linnaeus, 1758), to 3.7040, for *P. corythaeola.* Regarding growth type, it was observed that five species showed strong negative allometric growth ($b < 2.5$), 12 species showed a tendency to negative allometric growth ($b < 3$), eight species showed isometric growth ($b = 3$), 46 species showed a tendency to positive allometric growth ($b > 3$), and three species showed strong positive allometric growth ($b > 3.5$). These results are in agreement with those observed by Froese [17] where, after analyzing data from 2989 species from FISHBASE [22], he showed that 90% of the *b* parameter values were between 2.5 and 3.5.

The results of plotting *log a* vs. *b* are shown in Figure 2. Three possible outliers were identified through the model residuals vs. leverage plot (Figure 3). Those outliers corresponded to the species *C. macrophthalma* ($a = 0.015$, $b = 2.16$), *C. conger* ($a = 0.0005$, $b = 3.278$), and *D. cuneata* ($a = 0.0454$, $b = 2.3162$). Froese [17] explains that the presence of outliers in the *log a* vs. *b* regression may be due to few observations for species, outliers in those observations, or a small size range; however, he also says that these outliers may come from species with different body shapes than other species, as is the case for this species, which have a more elongated body shape. These differences due to the body shape of the species can be observed in works such as [52], in which the authors demonstrated the existence of significant differences in the *log a* vs. *b* regression due to this factor.

Small red scorpionfish *Scorpaena notata* (Rafinesque, 1810) is the only one species whose values differ to both studies in the Gulf of Cádiz, having in this work a higher *b* value than those [23,35]. These differences could be explained by the differences in the number of specimens examined and by the high number of individuals with a higher length than the first maturity length, 8.8 cm [53].

LWR of *C. nebulosus* is referenced for the first time in the Gulf of Cadiz in this study, showing a higher *b* value than in works carried out in its natural distribution area [54,55].

The *a* and *b* parameters obtained in these LWRs come from samples taken monthly, therefore should be taken as annual averages for comparisons, since the data were not collected at any season preferentially. The existence of differences in the values of the *b* parameters may be due to several factors, such as differences in the number of specimens sampled, different depths between studies, bigger or smaller ranges in size, as well as the presence of specimens captured at a certain time of the year where they present different conditions. Likewise, the existence of possible biological or environmental differences between regions can cause these differences. Furthermore, LWRs are not constant throughout the year, varying according to certain factors such as food availability, sex, gonadal development, temperature, salinity, presence, or absence of small specimens or the spawning season [17,23,45,56–58]. Possible differences in species of commercial interest may also be due to the fact that the individuals used in this work came from discards, so the commercial sizes of these species have not been used. In addition, as in Borges et al. [34], juveniles and small sizes of some species are not present due to the selectivity of the net.

Table 1. Parameters obtained for LWR and statistical description for 74 fish species discarded by the trawl fleet in the Gulf of Cádiz (SW Spain): n: number of specimens analyzed, length in cm (minimum, maximum, mean, and standard deviation (SD)), weight in g (minimum, maximum, mean, and standard deviation (SD)), LWR parameters (*a*: intercept (95% confidence interval (95% CI)), *b*: slope (95% confidence interval (95% CI)), R^2: coefficient of determination and *p*-value) and type of growth (allometric (positive or negative) or isometric). In bold are marked species without parameters for LWR in the Gulf of Cádiz.

Family—Species	N	Length (cm)			Weight (g)			Parameters of the LWR				Growth Type
		Min.	Max.	Mean (±SD)	Min.	Max.	Mean (±SD)	*a* (95% CI)	*b* (95% CI)	R^2	*p*-Value	
Batrachoididae												
Halobatrachus didactylus	23	13.5	33.5	21.72 (±4.89)	38.96	556.67	214.43 (±139.77)	0.0114 (0.0036–0.0317)	3.1464 (2.6152–3.6753)	0.962	<0.001	Allometric +
Blennidae												
Blennius ocellaris	29	4.3	14.7	11.18 (±2.39)	0.83	45.91	21.76 (±11.90)	0.0092 (0.0063–0.0133)	3.1641 (3.0100–3.3183)	0.985	<0.001	Allometric +
Callionymidae												
Callionymus lyra	12	2.7	20.2	10.91 (±5.82)	0.18	67.95	17.28 (±20.67)	0.0093 (0.0040–0.0214)	2.9038 (2.5409–3.2667)	0.966	<0.001	Allometric −
Callionymus maculatus	124	2.3	17.0	7.57 (±2.20)	0.09	36.57	2.83 (±3.37)	0.0152 (0.0124–0.0186)	2.4930 (2.3914–2.5946)	0.950	<0.001	Allometric −
Synchiropus phaeton	21	8.6	17.6	11.72 (±2.16)	3.75	44.71	10.87 (±9.01)	0.0037 (0.0012–0.0108)	3.1895 (2.7484–3.6305)	0.919	<0.001	Allometric +
Caproidae												
Capros aper	935	2.9	13.4	5.80 (±1.14)	0.59	44.00	4.46 (±3.60)	0.0246 (0.0228–0.0264)	2.8909 (2.8487–2.9331)	0.951	<0.001	Allometric −
Carangidae												
Trachurus mediterraneus	326	8.6	32.0	18.21 (±3.05)	4.83	239.30	48.72 (±31.07)	0.0099 (0.0086–0.0114)	2.8997 (2.8503–2.9491)	0.976	<0.001	Allometric −
Trachurus picturatus	95	12.2	17.5	14.34 (±1.31)	14.1	50.65	26.09 (±8.06)	0.0059 (0.0037–0.0093)	3.1430 (2.9713–3.3148)	0.934	<0.001	Allometric +
Trachurus trachurus	2333	5.2	32.6	16.79 (±3.97)	0.91	316.43	44.74 (±35.44)	0.0064 (0.0061–0.0068)	3.0752 (3.0562–3.0943)	0.977	<0.001	Allometric +
Centracanthidae												
Spicara flexuosa	36	9.1	20.4	16.83 (±2.30)	6.78	101.76	57.62 (±22.96)	0.0042 (0.0027–0.0076)	3.3491 (3.1381–3.5602)	0.967	<0.001	Allometric +
Spicara smaris	33	6.1	18.7	14.95 (±2.82)	2.12	73.39	40.56 (±18.54)	0.0081 (0.0055–0.0117)	3.1140 (2.9646–3.2533)	0.985	<0.001	Allometric +
Centriscidae												
Macroramphosus scolopax	17	5.6	13.2	9.21 (±2.30)	0.95	10.91	4.93 (±3.12)	0.0086 (0.0047–0.0155)	2.8016 (2.5334–3.0697)	0.969	<0.001	Allometric −
Cepolidae												
Cepola macrophthalma	148	7.8	63.8	26.41 (±11.17)	0.96	107.63	21.70 (±19.37)	0.0153 (0.0126–0.0186)	2.1607 (2.0999–2.2214)	0.971	<0.001	Allometric −

Table 1. *Cont.*

Family—Species	N	Length (cm)			Weight (g)			Parameters of the LWR				Growth Type
		Min.	Max.	Mean (±SD)	Min.	Max.	Mean (±SD)	*a* (95% CI)	*b* (95% CI)	R^2	*p*-Value	
Chlorophthalmidae												
Chlorophthalmus agassizi	5	10.8	14.8	13.72 (±1.68)	7.75	23.95	18.31 (±6.21)	0.0033 (0.0000–0.2701)	3.2756 (1.5900–4.9612)	0.903	0.008	Allometric +
Chimaeridae												
Chimaera monstrosa	17	22.0	78.5	38.07 (±17.44)	6.89	375.40	62.80 (±90.29)	0.0152 (0.0124–0.0186)	2.4930 (2.3914–2.5946)	0.950	<0.001	Allometric −
Citharidae												
Citharus linguatula	608	4.8	19.3	11.41 (±2.35)	0.81	55.33	12.34 (±7.31)	0.0052 (0.0047–0.0058)	3.1339 (3.0904–3.1773)	0.971	<0.001	Allometric +
Clupeidae												
Alosa alosa	17	20.2	42.2	29.88 (±5.45)	71.60	721.44	246.19 (±173.52)	0.0030 (0.0001–0.0071)	3.2949 (3.0383–3.5515)	0.979	<0.001	Allometric +
Alosa fallax	53	14.0	44.0	31.56 (±5.77)	21.81	878.17	276.23 (±146.39)	0.0090 (0.0058–0.0141)	2.9626 (2.8330–3.0923)	0.976	<0.001	Allometric −
Sardina pilchardus	1026	8.0	20.9	13.97 (±3.09)	2.64	83.89	24.22 (±16.39)	0.0071 (0.0065–0.0078)	3.0259 (2.9911–3.0676)	0.966	<0.001	Isometric
Congridae												
Conger conger	319	21.2	77.1	34.95 (±7.46)	6.40	868.95	63.60 (±62.74)	0.0005 (0.0003–0.0007)	3.2778 (3.1199–3.4086)	0.888	<0.001	Allometric +
Cynoglossidae												
Symphurus nigrescens	132	5.2	12.3	9.12 (±1.54)	1.03	16.77	7.48 (±3.80)	0.0050 (0.0038–0.0065)	3.2620 (3.1403–3.3837)	0.956	<0.001	Allometric +
Engraulidae												
Engraulis encrasicolus	3231	4.0	16.7	10.10 (±2.08)	0.31	24.46	6.58 (±4.18)	0.0045 (0.0042–0.0048)	3.0916 (3.0629–3.1202)	0.933	<0.001	Allometric +
Etmopteridae												
Etmopterus spinax	412	9.3	33.7	16.11 (±4.75)	2.85	144.48	19.76 (±23.34)	0.0029 (0.0025–0.0035)	3.0652 (3.0018–3.1285)	0.957	<0.001	Allometric +
Gadidae												
Gadiculus argenteus	158	6.4	16.1	9.49 (±1.60)	1.71	48.98	8.55 (±5.33)	0.0047 (0.0037–0.0061)	3.2816 (3.1694–3.3938)	0.955	<0.001	Allometric +
Micromesistius poutassou	208	12.8	29.1	20.77 (±2.95)	11.32	158.3	56.66 (±25.58)	0.0022 (0.0016–0.0028)	3.3292 (3.2412–3.4171)	0.964	<0.001	Allometric +
Trisopterus luscus	8	18.1	23.0	20.41 (±1.66)	62.00	126.15	94.21 (±21.56)	0.0190 (0.0030–0.1204)	2.8157 (2.2034–3.4280)	0.947	<0.001	Allometric −

Table 1. *Cont.*

Family—Species	N	Length (cm)			Weight (g)			Parameters of the LWR				Growth Type
		Min.	Max.	Mean (±SD)	Min.	Max.	Mean (±SD)	*a* (95% CI)	*b* (95% CI)	R^2	*p*-Value	
Gobiidae												
Aphia minuta	293	3.0	5.7	4.55 (±0.47)	0.16	1.16	0.50 (±0.17)	0.0060 (0.0043–0.0083)	2.8875 (2.6734–3.1016)	0.707	<0.001	Allometric −
Gobius niger	167	4.7	10.0	6.96 (±1.18)	0.78	11.17	3.53 (±2.06)	0.0056 (0.0047–0.0067)	3.2623 (3.1687–3.3559)	0.966	<0.001	Allometric +
Haemulidae												
Pomadasys incisus	613	4.5	22.9	11.28 (±4.33)	0.88	166.60	27.06 (±28.30)	0.0074 (0.0071–0.0077)	3.2049 (3.1875–3.2222)	0.995	<0.001	Allometric +
Lophiidae												
Lophius budegassa	241	4.3	27.7	9.74 (±3.42)	1.09	348.68	17.07 (±34.35)	0.0110 (0.0094–0.0129)	3.0354 (2.9650–3.1059)	0.968	<0.001	Isometric
Lophius piscatorius	68	5.0	28.5	10.78 (±4.08)	1.51	426.83	25.14 (±53.21)	0.0102 (0.0074–0.0139)	3.0723 (2.9394–3.2052)	0.927	<0.001	Allometric +
Merluccidae												
Merluccius merluccius	396	5.0	27.1	10.61 (±2.90)	0.69	128.95	8.96 (±10.68)	0.0047 (0.0042–0.0052)	3.0906 (3.0421–3.1390)	0.976	<0.001	Allometric +
Mugilidae												
Chelon ramada	48	24.3	43.6	30.59 (±4.38)	97.30	716.75	244.44 (±134.11)	0.0017 (0.0009–0.0034)	3.4406 (3.2398–3.6413)	0.962	<0.001	Allometric +
Pentanchidae												
Galeus melastomus	169	12.7	57.7	21.21 (±6.12)	5.33	492.47	31.57 (±44.53)	0.0024 (0.0018–0.0031)	3.0201 (2.9315–3.1087)	0.964	<0.001	Isometric
Peristediidae												
Peristedion cataphractum	16	11.1	25.1	16.36 (±4.07)	6.33	87.19	27.45 (±24.98)	0.0025 (0.0015–0.0042)	3.2481 (3.0700–3.4262)	0.990	<0.001	Allometric +
Phycidae												
Phycis blennoides	24	6.3	16.2	12.74 (±2.33)	1.34	26.46	12.58 (±5.69)	0.0039 (0.0026–0.0058)	3.1366 (2.9813–3.2920)	0.987	<0.001	Allometric +
Phosichthydae												
Polymetme corythaeola	5	15.6	21.5	17.98 (±2.23)	15.09	49.71	26.89 (±13.51)	0.0006 (0.0002–0.0016)	3.7040 (3.3378–4.0702)	0.996	<0.001	Allometric +

Table 1. *Cont.*

Family—Species	N	Length (cm)			Weight (g)			Parameters of the LWR				Growth Type
		Min.	Max.	Mean (±SD)	Min.	Max.	Mean (±SD)	*a* (95% CI)	*b* (95% CI)	R^2	*p*-Value	
Sciaenidae												
Cynoscion nebulosus	36	16.6	25.5	19.86 (±1.8)	52.10	194.85	89.49 (±30.1)	0.0073 (0.0033–0.0160)	3.1388 (2.8755–3.4020)	0.945	<0.001	Allometric +
Umbrina canariensis	18	12.2	27.3	20.27 (±4.76)	20.17	243.59	118.31 (±72.17)	0.0093 (0.0061–0.0144)	3.0887 (2.9449–3.2326)	0.992	<0.001	Allometric +
Umbrina ronchus	62	10.2	26.3	17.03 (±3.13)	11.27	211.46	66.04 (±42.14)	0.0101 (0.0070–0.0145)	3.0603 (2.9312–3.1893)	0.974	<0.001	Allometric +
Scombridae												
Scomber colias	52	17.4	28.0	21.87 (±2.10)	38.35	206.52	87.51 (±28.95)	0.0095 (0.0033–0.0274)	2.9487 (2.6048–3.2926)	0.853	<0.001	Allometric −
Scomber scombrus	48	13.4	31.0	25.58 (±4.77)	12.07	241.2	140.52 (±63.81)	0.0037 (0.0022–0.0060)	3.2227 (3.0708–3.3746)	0.975	<0.001	Allometric +
Scophthalmidae												
Lepidorhombus whiffiagonis	55	7.8	13.8	11.29 (±1.48)	1.89	17.26	9.24 (±3.74)	0.0015 (0.0009–0.0026)	3.5651 (3.3406–3.7896)	0.949	<0.001	Allometric +
Scorpaenidae												
Scorpaena notata	71	5.8	17.0	11.85 (±2.17)	3.35	103.32	36.70 (±20.77)	0.0137 (0.0102–0.0186)	3.1475 (3.0255–3.2695)	0.974	<0.001	Allometric +
Scyliorhinidae												
Scyliorhinus canicula	261	9.5	56.5	26.54 (±10.78)	2.44	651.10	91.06 (±126.76)	0.0021 (0.0017–0.0027)	3.0907 (3.0188–3.1626)	0.965	<0.001	Allometric +
Sebastidae												
Helicolenus dactylopterus	109	4.4	16.9	7.93 (±2.33)	1.24	80.78	10.18 (±11.92)	0.0111 (0.0097–0.0127)	3.1499 (3.0833–3.2165)	0.988	<0.001	Allometric +
Serranidae												
Serranus cabrilla	3	18.4	23.8	20.23 (±3.09)	72.78	181.95	109.9 (±62.41)	0.0025 (0–1.3845)	3.5373 (1.4275–5.6471)	0.996	0.030	Allometric +
Serranus hepatus	1519	3.4	14.5	9.20 (±1.74)	0.52	44.06	14.33 (±7.83)	0.0105 (0.0098–0.0112)	3.1996 (3.1696–3.2296)	0.966	<0.001	Allometric +

Table 1. *Cont.*

Family—Species	N	Length (cm)			Weight (g)			Parameters of the LWR				Growth Type
		Min.	Max.	Mean (±SD)	Min.	Max.	Mean (±SD)	*a* (95% CI)	*b* (95% CI)	R^2	*p*-Value	
Soleidae												
Dicologlossa cuneata	89	6.4	21.5	11.61 (±3.27)	2.70	72.22	15.07 (±10.58)	0.0454 (0.0328–0.0629)	2.3162 (2.1823–2.4501)	0.931	<0.001	Allometric −
Microchirus boscanion	822	4.9	17.4	8.87 (±1.37)	1.14	38.42	8.26 (±3.91)	0.0074 (0.0066–0.0083)	3.1777 (3.1232–3.2321)	0.941	<0.001	Allometric +
Microchirus ocellatus	27	5.2	15.4	12.04 (±2.24)	2.17	55.67	28.34 (±11.51)	0.0146 (0.0090–0.0240)	3.0070 (2.8067–3.2074)	0.974	<0.001	Isometric
Microchirus variegatus	88	4.9	15.8	9.31 (±2.31)	0.99	39.46	10.32 (±8.31)	0.0084 (0.0055–0.0128)	3.1033 (2.9134–3.2932)	0.924	<0.001	Allometric +
Solea solea	20	9.3	19.8	13.87 (±2.75)	7.49	81.99	28.08 (±17.38)	0.0090 (0.0054–0.0151)	3.0161 (2.8189–3.2132)	0.982	<0.001	Isometric
Sparidae												
Boops boops	422	6.7	31.2	19.96 (±4.40)	2.19	346.72	91.15 (±63.12)	0.0051 (0.0046–0.0057)	3.2137 (3.1789–3.2485)	0.987	<0.001	Allometric +
Dentex canariensis	28	11.9	23.7	16.33 (±3.21)	25.35	172.78	69.13 (±43.38)	0.0214 (0.0150–0.0305)	2.8567 (2.7290–2.9842)	0.987	<0.001	Allometric −
Diplodus annularis	698	4.7	18.6	10.81 (±2.62)	1.05	113.72	22.41 (±16.30)	0.0069 (0.0064–0.0074)	3.3140 (3.2849–3.3430)	0.986	<0.001	Allometric +
Diplodus bellottii	923	4.7	20.0	10.55 (±2.82)	1.10	130.16	20.88 (±18.51)	0.0070 (0.0066–0.0073)	3.2896 (3.2689–3.3103)	0.991	<0.001	Allometric +
Diplodus vulgaris	181	10.6	22.8	18.31 (±2.60)	15.36	185.72	98.52 (±39.93)	0.0068 (0.0056–0.0083)	3.2699 (3.2001–3.3396)	0.979	<0.001	Allometric +
Pagellus acarne	58	12.3	22.6	17.60 (±2.08)	20.13	143.09	69.94 (±25.60)	0.0107 (0.0069–0.0167)	3.0477 (2.8926–3.2029)	0.965	<0.001	Allometric +
Pagellus bellottii	596	5.3	23.4	15.34 (±2.73)	1.76	196.04	49.71 (±23.80)	0.0091 (0.0084–0.0098)	3.1171 (3.0875–3.1467)	0.986	<0.001	Allometric +
Pagellus erythrinus	401	4.7	27.8	14.20 (±4.34)	1.33	195.94	44.98 (±36.33)	0.0117 (0.0107–0.0128)	3.0155 (2.9810–3.0499)	0.987	<0.001	Isometric
Pagrus auriga	6	15.0	22.3	18.12 (±2.56)	57.77	192.16	110.69 (±47.79)	0.0142 (0.0044–0.0454)	3.0760 (2.6735–3.4786)	0.989	<0.001	Allometric +
Spondyliosoma cantharus	281	9.4	26.4	17.96 (±4.17)	10.14	347.63	91.57 (±57.74)	0.0101 (0.0086–0.0119)	3.0967 (3.0413–3.1521)	0.977	<0.001	Allometric +
Syngnathidae												
Hippocampus hippocampus	6	7.2	11.1	9.47 (±1.62)	1.72	6.14	3.97 (±1.74)	0.0148 (0.0002–0.9529)	2.4595 (0.5570–4.3621)	0.704	0.023	Allometric −
Torpedinidae												
Torpedo marmorata	97	10.9	45.0	20.87 (±7.17)	28.35	2288.71	262.32 (±320.93)	0.0322 (0.0258–0.0401)	2.8698 (2.7963–2.9433)	0.984	<0.001	Allometric −
Trachinidae												
Echiichthys vipera	42	9.9	27.7	16.91 (±3.09)	6.02	166.17	32.03 (±24.63)	0.0057 (0.0035–0.0094)	3.0084 (2.8350–3.1818)	0.968	<0.001	Isometric
Trachinus draco	156	5.7	25.0	16.43 (±3.30)	1.05	100.23	29.15 (±14.87)	0.0074 (0.0063–0.0086)	2.9211 (2.8647–2.9775)	0.985	<0.001	Allometric −

Table 1. *Cont.*

Family—Species	N	Length (cm)			Weight (g)			Parameters of the LWR				Growth Type
		Min.	Max.	Mean (±SD)	Min.	Max.	Mean (±SD)	*a* (95% CI)	*b* (95% CI)	R^2	*p*-Value	
Triglidae												
Chelidonichthys lastoviza	12	11.4	22.8	19.17 (±3.73)	14.75	141.15	80.33 (±43.12)	0.0050 (0.0008–0.0321)	3.2378 (2.6009–3.8747)	0.921	<0.001	Allometric +
Chelidonichthys lucerna	24	4.1	34.0	14.66 (±10.01)	0.74	494.31	70.93 (±117.70)	0.0147 (0.0108–0.0200)	2.8274 (2.7067–2.9480)	0.990	<0.001	Allometric −
Chelidonichthys obscurus	51	8.6	22.5	16.62 (±2.76)	4.67	87.59	40.07 (±19.61)	0.0055 (0.0038–0.0079)	3.1343 (3.0046–3.2641)	0.979	<0.001	Allometric +
Lepidotrigla cavillone	207	3.9	22.5	8.845 (±2.23)	0.54	93.29	9.00 (±9.17)	0.0079 (0.0070–0.0090)	3.1298 (3.0721–3.1874)	0.982	<0.001	Allometric +
Lepidotrigla dieuzeidei	160	2.7	13.9	10.26 (±2.54)	0.24	30.00	14.32 (±8.55)	0.0076 (0.0067–0.0087)	3.1594 (3.1036–3.2151)	0.988	<0.001	Allometric +
Trigla lyra	4	16.0	26.6	21.07 (±4.39)	34.74	169.89	91.33 (±57.93)	0.0054 (0.0006–0.0481)	3.1603 (2.4390–3.8815)	0.992	0.003	Allometric +
Uranoscopidae												
Uranoscopus scaber	8	14.7	24.5	21.00 (±3.17)	49.01	286.15	170.04 (±77.61)	0.0055 (0.0007–0.0446)	3.3674 (2.6799–4.0550)	0.953	<0.001	Allometric +

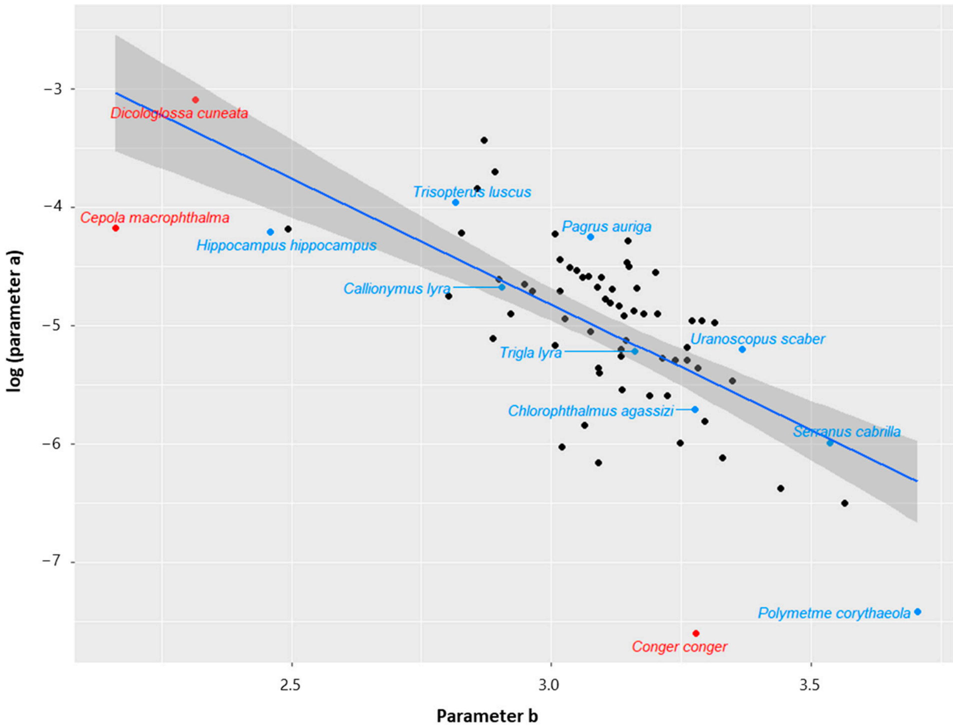

Figure 2. Plot of *log a* vs. *b* for the LWRs for the 74 fish species studied. Red points are species with outlier values. Blue points are species with a low number of individuals caught. Black points are the other species analysed.

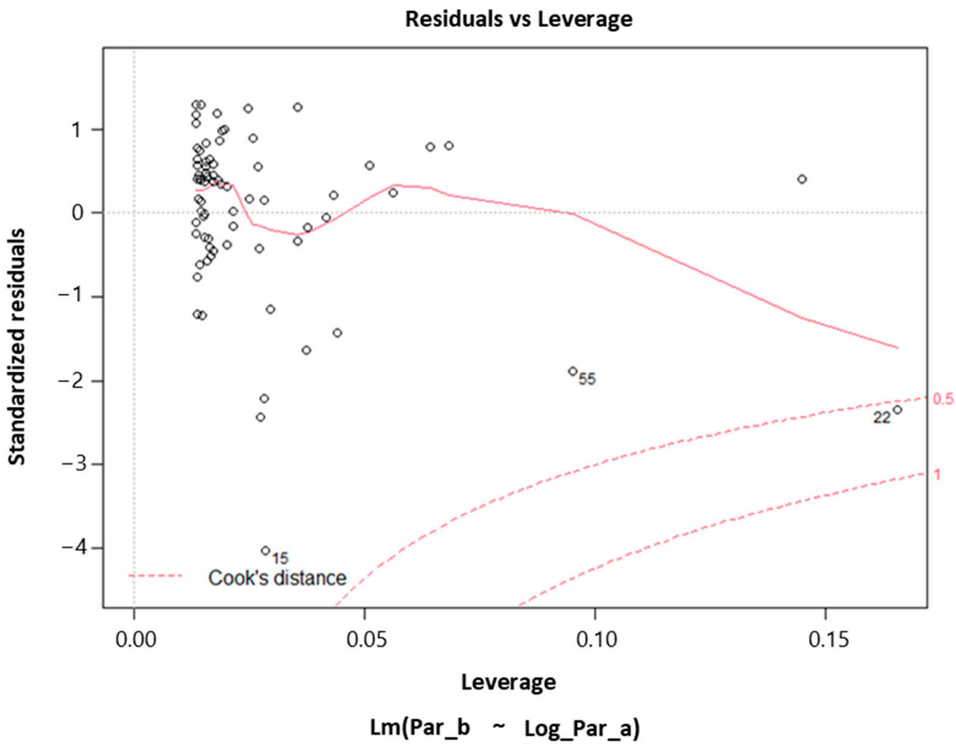

Figure 3. Residuals vs. Leverage plot. Circles represent individual observations. The solid red line represents a residual regression line that should be close to zero. The dashed red lines indicate influence limits (Cook's distance; 0.5 and 1) used to identify potential outliers. Observations 15, 22, and 55 have been identified as influential points in the analysis.

Low-Sample Specimens

For the low-sampled specimens (n < 12) further use of LWR should be limited to the size ranges used for the estimation of the parameters [18]. The LWRs of some individuals are biased due to the sample collection method and low sample size, but they are included in this paper because they are the first reports of these species in the study area. The number of studies that are available for each of these species in the global FishBase database are in Table 2. Redbanded seabream *Pagrus auriga* (Valenciennes, 1843) and *P. corythaeola* only have one LWR available in FishBase. In particular, *P. auriga* LWR had obtained with only one individual, keeping *b* constant (*b* = 3), giving a value of parameter *a* = 0.0191, similar to that obtained in this work (*a* = 0.0142).

Table 2. Number of studies available in FishBase [24] for nine species with a low number of individuals: Mean N: mean number of individuals of studies available in FishBase, Geometric Mean *a* and Mean *b* are values of parameter *a* and parameter *b* calculated by FishBase from all available studies. *Pagrus auriga* LWR was obtained by keeping the *b*-parameter constant at three (marked with *).

Species	Number of Studies	Mean N	Geometric Mean *a*	Mean *b*
Polymetme corythaeola	1	9	0.0034	3.1160
Pagrus auriga	1	1	0.0191	3.0000 *
Hippocampus hippocampus	4	49	0.0023	3.0000
Chlorophthalmus agassizi	8	226	0.0049	3.1100
Callionymus lyra	11	262	0.0166	2.6900
Trisopterus luscus	14	395	0.0081	3.1400
Trigla lyra	15	742	0.0110	2.9400
Uranoscopus scaber	21	95	0.0141	3.0500
Serranus cabrilla	35	243	0.0170	2.8600

Given the lack of information about some of those individuals, these first estimates may be useful in future research for this and other adjacent areas. A comparison was made between the results obtained in this study for nine species with low abundance values with those of other studies carried out on adjacent study areas (Southern Portugal) [32–34,36,59] (Table 3). Specifically, it was observed that all species had similar or higher *b* values than those obtained in these works, except for Piper gurnard *Trigla lyra* (Linnaeus, 1758), dragonet *Callionymus lyra* (Linnaeus, 1758), and pouting *Trisopterus luscus* (Linnaeus, 1758), which had lower *b* values. This result is likely because these individuals with low *b* values are still growing and allocating energy towards developing their reproductive organs, which may lead to a less efficient conversion of food into biomass [60–62]. On the other hand, fish that have reached sexual maturity and are at their maximum length have been shown to have a value of *b* > 3, indicating a more rapid increase in weight compared to length [63–67]. This increase in weight is likely due to the allocation of resources towards reproduction, as mature fish must invest a significant amount of energy into producing and carrying eggs or sperm. Therefore, the differences in the value of *b* between our study and others are likely due to differences in the length and sexual maturity of the fish, highlighting the importance of considering these factors when interpreting the weight–length relationship in fish. In addition to this factor, it has been observed that LWRs can vary whether individuals are captured in warm or cold periods, as well as depending on the season [68], variables that, together with the low sample size, may explain these variations.

Table 3. Comparison of sample sizes and LWR parameters of the nine species with lowest sample size with other studies from adjacent study areas (southern Portugal waters). Key: n, number of specimens analyzed; *a*, intercept of the LWR; *b*, slope of the LWR.

	Our Work			[32]			[33]			[34]			[59]			[36]		
Species	**n**	***a***	***b***	**n**	***a***	***b***	**n**	***a***	***b***	**n**	***a***	***b***	**n**	***a***	***b***	**n**	***a***	***b***
Serranus cabrilla	3	0.0025	3.5373	171	0.00007337	2.6610	51	0.0729	2.4100	-	-	-	95	0.0213	2.7760	-	-	-
Trigla lyra	4	0.0054	3.1603	-	-	-	15	0.0217	2.7350	7	0.00858	3.1380	42	0.0056	3.1230	-	-	-
Chlorophthalmus agassizi	5	0.0033	3.2756	-	-	-	-	-	-	6	0.00786	2.9090	-	-	-	-	-	-
Polymetme corythaeola	5	0.0006	3.7040	-	-	-	-	-	-	9	0.00337	3.1160	-	-	-	-	-	-
Pagrus auriga	6	0.0142	3.0760	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hippocampus hippocampus	6	0.0148	2.4595	-	-	-	-	-	-	-	-	-	-	-	-	9	0.0064	2.7300
Trisopterus luscus	8	0.0190	2.8157	22	0.00001921	2.9310	56	0.0031	3.4400	-	-	-	1700	0.0089	3.0850	-	-	-
Uranoscopus scaber	8	0.0055	3.3674	-	-	-	-	-	-	-	-	-	33	0.0305	2.8290	-	-	-
Callionymus lyra	12	0.0093	2.9038	24	0.00084177	2.1170	235	0.1053	2.1070	31	0.05630	2.3100	60	0.0800	2.1710	24	0.0078	3.0200

Despite the valuable insights provided by this study, there are some limitations that should be acknowledged. First, as mentioned earlier, the sample sizes for some species were small, which may affect the accuracy of the LWR estimates [17]. Second, this study focused on discarded fish species, which does not fully represent the fish community in the Gulf of Cadiz. Third, the study did not account for possible seasonal variations in the LWRs, which may influence the results. Regardless of these considerations, studies such as this one, are essential for the knowledge of the species and their management when there are few data in a given area.

4. Conclusions

The use of small sample sizes in fisheries research may lack statistical power or be subject to bias. However, in this study, we argue that even with a small sample size, the weights–length relationship of discarded fish can still provide valuable insights into the biology and ecology of fish populations. Our results demonstrate that the parameter "*b*" in the LWR of fish can provide a useful indicator of maturity and reproductive biology, even with a small sample size. Furthermore, by including data from discarded fish, we can gain a better understanding of the population dynamics and life history strategies of fish species, which can inform conservation and management efforts. Therefore, we believe that the inclusion of weight–length data from small sample sizes can still be a valuable tool for fisheries research, provided that appropriate statistical methods and careful consideration of potential biases are employed. Due to the fact that LWRs depend on the temporal moment in which the data were taken [15], knowing what these LWRs are like for the different species in an area over time is very useful for the knowledge and management of the populations in that study area. This is more important for discarded species due to possible interspecific relationships, since these species may have an influence on species of commercial interest in, for example, food webs [5,69].

It is hoped that the results of this study will contribute to the knowledge of the species and populations in this area, as well as to future management, conservation, and recovery plans for exploited species.

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Institutional Review Board Statement: The specimens used in this work have never been subjected to animal experimentation. These specimens come from catches made by professional fishermen and are subject to European regulations on Fish.

Informed Consent Statement: Not applicable.

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