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**LENGTH-WEIGHT RELATIONSHIP OF JACK MACKEREL  
(*Trachurus murphyi*) IN PERU AND ITS IMPLICATIONS FOR  
BIOMASS ESTIMATION**

by

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This report contains information on the jack mackerel fish stock and fishery in Peruvian jurisdictional waters that, we reiterate, the delegation of Peru, in use of its discretionary powers, voluntarily provides for the purpose of information and support to the scientific research work within the Scientific Committee of the SPRFMO. In doing so, while referring to Article 5 of the Convention on the Conservation and Management of High Seas Fishery Resources in the South Pacific Ocean and reiterating that Peru has not given the express consent contemplated in Article 20 (4) (a) (iii) of the Convention, Peru reaffirms that the decisions and conservation and management measures adopted by the SPRFMO Commission are not applicable within Peruvian jurisdictional waters.

## ABSTRACT

The length–weight (L–W) relationship is a fundamental tool in fisheries biology used to convert length data into biomass and to indirectly assess fish body condition. The present study analyzes this relationship in jack mackerel (*Trachurus murphyi*) using a historical series of biological data collected over 55 years (1971–2025) along the Peruvian coast.

The relationship was modeled using the allometric equation:  $W = aL^b$ . The model parameters and their 95% confidence intervals were estimated. A total of 220,570 individuals obtained from biological samplings conducted by the Instituto del Mar del Perú were analyzed. The estimated allometric coefficient was  $b = 2.881$  (95% CI: 2.8797 - 2.8834), indicating an allometric growth pattern with a high model fit ( $R^2 = 0.97$ ), demonstrating a strong relationship between length and weight.

Marked temporal variability was identified in parameter  $b$ , with decreases coinciding with periods associated with warm El Niño–Southern Oscillation (ENSO) events. These fluctuations suggest a significant influence of environmental changes on the body condition and growth of the stock. Likewise, weight-at-age estimates showed a progressive increase in body weight with increasing fish age.

The results demonstrate that the jack mackerel L–W relationship is not stationary; therefore, the use of constant parameters may introduce biases in biomass estimates used in stock assessments. In this context, the incorporation of dynamic parameterization schemes into fisheries models is recommended, particularly in highly variable ecosystems such as the Humboldt Current System.

**Keywords:** length-weight relationship, jack mackerel (*Trachurus murphyi*), biomass, allometry, stock assessment.

## 1. INTRODUCTION

Jack mackerel (*Trachurus murphyi*) is one of the main pelagic species of the southeastern Pacific Ocean and represents a resource of major ecological and fisheries importance in the Humboldt Current System. The population dynamics of this species are strongly influenced by the oceanographic variability of this ecosystem (PAULY, 1980; SERRA, 1991; DIOSES, 2013; ESPINO, 2013), particularly by processes associated with coastal upwelling and El Niño–Southern Oscillation (ENSO) events.

Its ecological and economic importance in industrial and artisanal fisheries has promoted the development of robust methodologies for estimating key biological parameters required for stock assessment (CARVALHO *et al.*, 2021; CUBILLOS & CUEVAS, 2023). The proper parameterization of stock assessment models critically depends on the quality of the biological parameters used. Among these, the length-weight (L-W) relationship constitutes a fundamental tool in fisheries biology because it allows the conversion of length-frequency data into biomass and provides indirect information on fish body condition (FROESE, 2006; PAULY, 1984). This relationship is described by the allometric model:  $W = aL^b$  where  $W$  is total weight,  $L$  is length, and  $a$  and  $b$  represent species and population-specific parameters. The parameter  $b$  allows inference of the type of body growth (isometric or allometric), whereas  $a$  is associated with morphological characteristics and body condition.

The theoretical basis of this relationship dates back to the so called “square–cube law” proposed by Galileo Galilei and later reformulated as the “cube law,” which states that body volume and weight increase proportionally to the cube of length. However, several empirical studies demonstrated that fish growth frequently deviates from isometric growth due to the influence of physiological, environmental, and ontogenetic factors (FULTON, 1904; LE CREN, 1951).

The parameters of the L-W relationship may vary significantly according to environmental, ontogenetic, spatial, and temporal factors (FROESE, 2006; PAULY, 1984). Nevertheless, many stock assessments implicitly assume that these parameters remain constant over time, which could introduce biases in biomass estimation and population assessment of species subjected to high environmental variability.

Likewise, weight-at-age is a fundamental parameter in age-structured models due to its application in biomass, mortality, and fisheries yield estimates. However, this parameter is rarely observed directly; therefore, its estimation is generally based on the integration of fundamental biological relationships. In this context, weight-at-age is commonly estimated by integrating the von Bertalanffy growth function with the length–weight relationship. The von Bertalanffy growth function has been widely used to describe growth in length, whereas the length–weight relationship allows the conversion of these estimates into individual biomass.

In Peru, the parameters of the jack mackerel L-W relationship are routinely used in stock assessments conducted by the Instituto del Mar del Perú (IMARPE, 2025; IMARPE, 2024). However, there is limited information regarding their temporal stability and their potential implications for biomass estimation over long-term temporal scales.

The objectives of the present study were: (i) to estimate the length-weight (L-W) relationship of jack mackerel using a historical series of biological data collected between 1971 and 2025; (ii) to evaluate the temporal variability of its parameters; and (iii) to estimate weight-at-age by integrating the L-W relationship and the von Bertalanffy growth function, emphasizing their implications for biomass estimation and stock assessment.

## 2. MATERIALS AND METHODS

### 2.1 Data

A total of 220,570 jack mackerel individuals were analyzed from biological samplings conducted by the Instituto del Mar del Perú (IMARPE) between 1971 and 2025 along the Peruvian coast (3°S - 18°S). The database included records of total length (TL, cm), total weight (W, g), sex (males and females), sampling date, and landing port.

### 2.2 Length - weight relationship

The length - weight (L-W) relationship was modeled using the allometric equation proposed by LE CREN (1951):

$$W = aL^b$$

where:

*W*: total weight (g)

*L*: total length (cm)

*a*: constant associated with the average condition factor

*b*: allometric exponent representing the average weight growth parameter.

The model was fitted using linear regression applied to log-transformed data according to the expression:

$$\log W = \log a + b \log L$$

Additionally, a direct nonlinear fit using the least-squares method was performed to evaluate the consistency of parameter estimates.

The parameters *a* and *b*, the standard error of *b*, and their 95% confidence intervals were estimated. Model fit quality was evaluated using the coefficient of determination ( $R^2$ ). The L-W relationship was estimated both for the entire dataset and on an annual basis in order to evaluate the temporal variability of the allometric parameter.

### 2.3 Weight-at-age estimation

Weight-at-age was estimated by integrating the von Bertalanffy growth function with the length-weight relationship: peso:

$$W(t) = a[L_{\infty}(1 - e^{-k(t-t_0)})]^b$$

The growth parameters reported by DIOSES (2013) were used: asymptotic length ( $L_{\infty}$ ) = 80.77 cm, growth coefficient (*k*) = 0.155, and theoretical age at length zero ( $t_0$ ) = -0.356. The estimated lengths were subsequently converted into weight using the L-W relationship, generating theoretical weight estimates for ages between 0 and 7 years.

### 3. RESULTS

#### 3.1 Length - weight relationship

The L-W relationship for the entire dataset showed a high level of statistical fit ( $R^2 = 0.97$ ), indicating a strong relationship between length and weight. The estimated allometric coefficient was  $b = 2.881$  (95% CI: 2.8794 - 2.8834), indicating an allometric growth pattern (Table 1 and Fig. 1). The results showed that the increase in length occurred proportionally at a higher rate than the increase in weight, a characteristic pattern of highly migratory pelagic species.

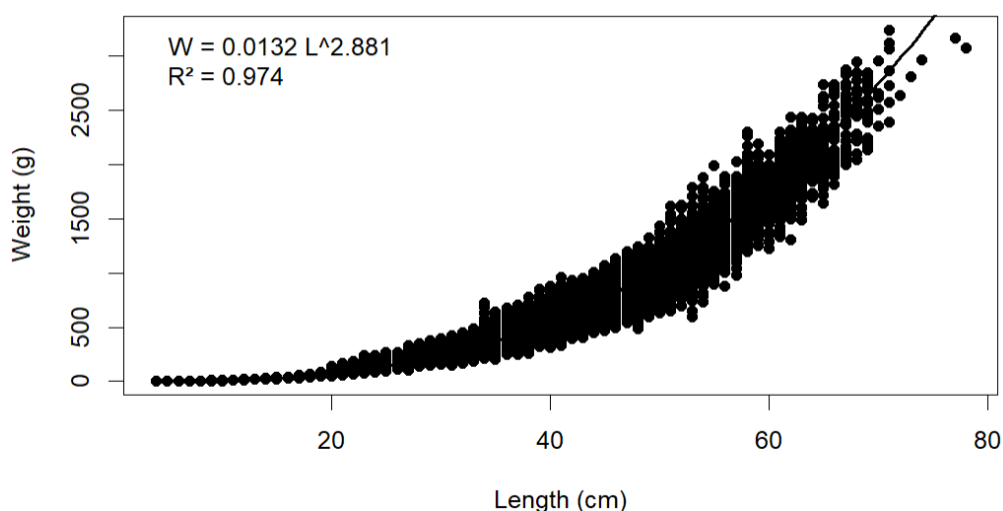


Figure 1. Overall length - weight (L-W) relationship of jack mackerel along the Peruvian coast during 1971–2025.

Table 1. Parameters of the overall length - weight relationship for jack mackerel along the Peruvian coast during 1971–2025.

Period	Parameters of the relationship				Standard error $b$	Confidence interval (IC 95%)	
	$n$	$a$	$b$	$R^2$		Lower limit	Upper limite
1971-2025	220570	0.0132	2.8810	0.9740	0.001	2.8794	2.8834

The temporal analysis of the allometric parameter  $b$  (Table 2 and Fig. 2) showed marked interannual variability throughout the analyzed period, with values ranging between allometric growth patterns and, in some years, values close to isometric growth. The predominance of values lower than 3 suggests that jack mackerel increase in length at a proportionally higher rate than in weight. However, the observed fluctuations indicate that the L-W relationship responds to environmental and biological changes in the Humboldt Current System. These results suggest that the use of constant parameters in the conversion of size into biomass could introduce biases in stock assessments.

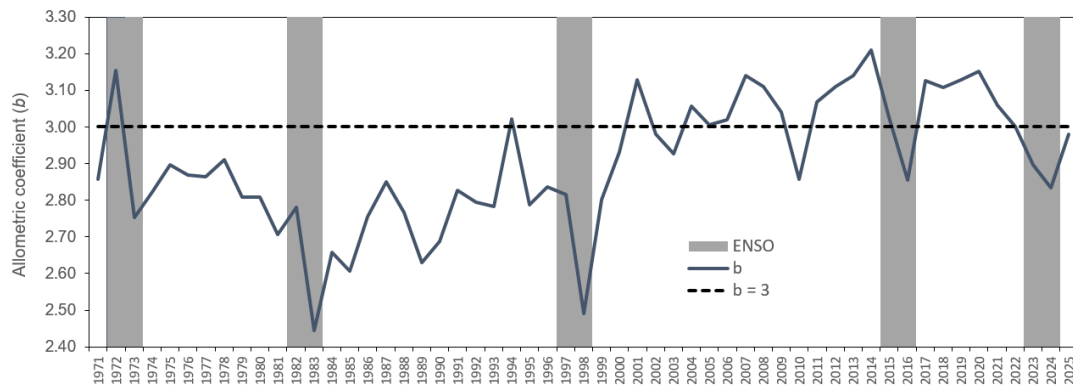


Figure 2. Temporal variability of the allometric parameter  $b$  in the length–weight relationship of jack mackerel (*Trachurus murphyi*) off Peru during 1971–2025. (Continuous line represents the allometric parameter  $b$ ; dashed line represents  $b = 3$ ; shaded bars indicate El Niño–Southern Oscillation - ENSO).

The decreases observed in the allometric parameter  $b$  partially coincided with periods associated with warm El Niño events, particularly during 1982–1983, 1997–1998, and 2015–2016, suggesting a possible physiological response of jack mackerel to extreme oceanographic changes. In the Humboldt Current System, these events alter upwelling intensity, primary productivity, and food availability, directly affecting the body condition and growth of pelagic species.

### 3.2 Weight-at-age estimation

The estimation of weight by age groups of jack mackerel in Peruvian waters during 1971 - 2025 (Table 3) showed a progressive increase in weight with age, consistent with the somatic growth of the species. The lowest values were recorded for age group 0 (<0.05 kg), whereas the highest values corresponded to age groups VI - VII, exceeding 1.5 kg in some years.

Likewise, interannual fluctuations in weight at the same age were observed, suggesting the influence of environmental variability, food availability, and population dynamics on individual growth. Overall, the results showed a relatively stable growth structure throughout the analyzed period.

## 4. DISCUSSION

The length–weight (L-W) relationship of jack mackerel (*Trachurus murphyi*) showed a high statistical fit ( $R^2 = 0.97$ ), confirming a strong association between both variables. The allometric coefficient ( $b = 2.881$ ) indicated an allometric growth pattern, in which weight increases at a lower rate than length, reflecting a more elongated body shape with increasing size, a characteristic typical of highly migratory pelagic species.

The marked temporal variability of parameter  $b$  demonstrates that the jack mackerel L-W relationship is not stationary, but rather responds to environmental and biological changes characteristic of the Humboldt Current System. Factors such as temperature, food availability, primary productivity, population structure, and reproductive status have been widely recognized as modulators of the L-W relationship (PAULY, 1980; PAULY, 1984; FROESE, 2006; WOOTTON, 1998; ALEGRE *et al.*, 2015).

Table 2. Parameters of the length–weight relationship of jack mackerel in peruvian waters during 1971–2025.

Year	Parameters of the relationship				Standard error <i>b</i>	Confidence interval (IC 95%)	
	<i>n</i>	<i>a</i>	<i>b</i>	<i>R</i> <sup>2</sup>		Lower limit	Upper límite
1971	327	0.0162	2.8574	0.9588	0.0328	2.7928	2.9220
1972	197	0.0046	3.1546	0.9899	0.0228	3.1096	3.1995
1973	478	0.0210	2.7517	0.9853	0.0154	2.7214	2.7820
1974	1400	0.0160	2.8217	0.9737	0.0124	2.7974	2.8461
1975	919	0.0117	2.8965	0.9922	0.0085	2.8799	2.9132
1976	1851	0.0129	2.8687	0.9510	0.0152	2.8389	2.8984
1977	4617	0.0126	2.8652	0.9753	0.0067	2.8520	2.8783
1978	4579	0.0106	2.9117	0.9704	0.0075	2.8970	2.9264
1979	3344	0.0153	2.8086	0.9717	0.0083	2.7924	2.8249
1980	2063	0.0154	2.8078	0.9672	0.0114	2.7854	2.8301
1981	1684	0.0232	2.7056	0.9727	0.0111	2.6839	2.7273
1982	1145	0.0176	2.7798	0.9822	0.0111	2.7581	2.8015
1983	1811	0.0528	2.4450	0.9199	0.0170	2.4117	2.4783
1984	2696	0.0285	2.6569	0.9221	0.0149	2.6277	2.6861
1985	1403	0.0350	2.6073	0.9692	0.0124	2.5829	2.6316
1986	2297	0.0199	2.7561	0.9755	0.0091	2.7383	2.7740
1987	1972	0.0134	2.8507	0.9882	0.0070	2.8369	2.8645
1988	2107	0.0195	2.7671	0.9733	0.0100	2.7475	2.7867
1989	2395	0.0326	2.6293	0.9645	0.0103	2.6091	2.6495
1990	2617	0.0258	2.6886	0.9612	0.0106	2.6679	2.7093
1991	4059	0.0154	2.8272	0.9597	0.0091	2.8094	2.8450
1992	3067	0.0172	2.7949	0.9511	0.0115	2.7724	2.8173
1993	1519	0.0183	2.7826	0.9662	0.0134	2.7564	2.8088
1994	817	0.0080	3.0223	0.9435	0.0259	2.9715	3.0732
1995	5323	0.0180	2.7881	0.9616	0.0076	2.7732	2.8031
1996	4009	0.0154	2.8357	0.9818	0.0061	2.8238	2.8477
1997	3609	0.0158	2.8145	0.9544	0.0102	2.7944	2.8345
1998	4808	0.0461	2.4912	0.9302	0.0098	2.4719	2.5105
1999	3513	0.0176	2.8021	0.9690	0.0085	2.7856	2.8187
2000	4179	0.0114	2.9324	0.9320	0.0123	2.9084	2.9564
2001	9443	0.0057	3.1285	0.9391	0.0082	3.1124	3.1446
2002	5297	0.0095	2.9801	0.9540	0.0090	2.9624	2.9977
2003	8410	0.0116	2.9268	0.9648	0.0061	2.9148	2.9387
2004	7189	0.0074	3.0564	0.9746	0.0058	3.0450	3.0678
2005	5017	0.0090	3.0051	0.9884	0.0046	2.9961	3.0141
2006	10873	0.0086	3.0191	0.9765	0.0045	3.0103	3.0279
2007	9286	0.0057	3.1397	0.9816	0.0045	3.1309	3.1484
2008	5585	0.0063	3.1105	0.9802	0.0059	3.0989	3.1221
2009	2744	0.0079	3.0409	0.9847	0.0072	3.0267	3.0550
2010	1934	0.0146	2.8565	0.9789	0.0095	2.8378	2.8752
2011	7282	0.0072	3.0675	0.9648	0.0069	3.0540	3.0809
2012	7190	0.0062	3.1094	0.9808	0.0051	3.0993	3.1195
2013	5255	0.0057	3.1410	0.9762	0.0068	3.1278	3.1543
2014	6692	0.0046	3.2098	0.9588	0.0081	3.1939	3.2258
2015	4043	0.0085	3.0265	0.9588	0.0099	3.0071	3.0458
2016	2674	0.0152	2.8539	0.9590	0.0114	2.8316	2.8763
2017	4567	0.0058	3.1265	0.9757	0.0073	3.1122	3.1409
2018	7345	0.0064	3.1078	0.9713	0.0062	3.0956	3.1201
2019	7749	0.0059	3.1287	0.9696	0.0063	3.1163	3.1410
2020	3314	0.0054	3.1507	0.9730	0.0091	3.1328	3.1686
2021	4438	0.0073	3.0589	0.9867	0.0053	3.0485	3.0694
2022	4224	0.0090	3.0001	0.9880	0.0051	2.9901	3.0101
2023	6525	0.0127	2.8967	0.9872	0.0041	2.8887	2.9048
2024	4777	0.0164	2.8338	0.9903	0.0041	2.8258	2.8417
2025	3912	0.0096	2.9800	0.9911	0.0045	2.9711	2.9889

Table 3. Weight by age groups of jack mackerel in Peruvian waters during 1971–2025

Year	Age Groups							
	<i>0</i>	<i>I</i>	<i>II</i>	<i>III</i>	<i>IV</i>	<i>V</i>	<i>VI</i>	<i>VII</i>
1971	0.039	0.155	0.346	0.598	0.888	1.200	1.517	1.829
1972	0.025	0.114	0.279	0.509	0.788	1.099	1.423	1.749
1973	0.038	0.143	0.311	0.525	0.770	1.028	1.289	1.543
1974	0.035	0.137	0.303	0.519	0.768	1.033	1.302	1.566
1975	0.032	0.127	0.288	0.500	0.748	1.015	1.287	1.555
1976	0.032	0.127	0.286	0.494	0.736	0.996	1.260	1.520
1977	0.032	0.125	0.281	0.486	0.723	0.978	1.238	1.493
1978	0.030	0.121	0.275	0.479	0.717	0.974	1.237	1.497
1979	0.033	0.125	0.275	0.471	0.696	0.935	1.177	1.414
1980	0.033	0.125	0.277	0.473	0.698	0.938	1.182	1.419
1981	0.037	0.136	0.291	0.489	0.711	0.946	1.181	1.409
1982	0.035	0.131	0.287	0.488	0.717	0.961	1.207	1.448
1983	0.042	0.134	0.268	0.427	0.599	0.775	0.947	1.111
1984	0.040	0.143	0.303	0.503	0.728	0.963	1.197	1.424
1985	0.043	0.150	0.312	0.514	0.738	0.971	1.203	1.426
1986	0.037	0.137	0.299	0.506	0.742	0.992	1.244	1.489
1987	0.032	0.125	0.280	0.482	0.716	0.966	1.221	1.471
1988	0.037	0.139	0.304	0.516	0.758	1.014	1.272	1.524
1989	0.043	0.150	0.314	0.519	0.748	0.986	1.224	1.453
1990	0.040	0.143	0.306	0.512	0.743	0.986	1.229	1.465
1991	0.034	0.133	0.296	0.508	0.752	1.012	1.276	1.535
1992	0.035	0.134	0.295	0.503	0.742	0.996	1.252	1.503
1993	0.036	0.138	0.302	0.513	0.755	1.012	1.271	1.525
1994	0.030	0.129	0.303	0.540	0.822	1.129	1.447	1.763
1995	0.036	0.138	0.303	0.515	0.759	1.018	1.279	1.535
1996	0.035	0.137	0.306	0.525	0.778	1.049	1.324	1.593
1997	0.034	0.132	0.291	0.499	0.737	0.991	1.249	1.501
1998	0.041	0.136	0.275	0.442	0.624	0.812	0.996	1.172
1999	0.037	0.141	0.311	0.530	0.782	1.051	1.322	1.588
2000	0.034	0.139	0.317	0.555	0.833	1.135	1.444	1.748
2001	0.029	0.129	0.311	0.565	0.873	1.213	1.568	1.924
2002	0.032	0.134	0.312	0.550	0.832	1.139	1.455	1.767
2003	0.034	0.139	0.316	0.553	0.831	1.131	1.438	1.740
2004	0.031	0.134	0.316	0.567	0.867	1.196	1.537	1.876
2005	0.033	0.138	0.323	0.573	0.870	1.193	1.527	1.858
2006	0.032	0.138	0.322	0.573	0.872	1.198	1.535	1.870
2007	0.030	0.134	0.324	0.590	0.912	1.269	1.642	2.015
2008	0.031	0.136	0.326	0.590	0.909	1.261	1.628	1.995
2009	0.032	0.136	0.321	0.573	0.874	1.204	1.545	1.885
2010	0.035	0.139	0.311	0.536	0.797	1.076	1.361	1.640
2011	0.031	0.135	0.321	0.578	0.884	1.221	1.571	1.919
2012	0.030	0.134	0.322	0.582	0.897	1.244	1.606	1.967
2013	0.030	0.136	0.329	0.600	0.928	1.291	1.671	2.052
2014	0.029	0.137	0.339	0.625	0.976	1.368	1.781	2.196
2015	0.033	0.140	0.328	0.584	0.889	1.223	1.568	1.910
2016	0.037	0.143	0.320	0.553	0.821	1.109	1.402	1.689
2017	0.030	0.132	0.318	0.578	0.892	1.240	1.602	1.966
2018	0.031	0.136	0.326	0.591	0.910	1.262	1.628	1.995
2019	0.030	0.133	0.322	0.586	0.904	1.257	1.625	1.994
2020	0.029	0.131	0.318	0.581	0.900	1.254	1.624	1.995
2021	0.031	0.133	0.314	0.563	0.862	1.189	1.528	1.866
2022	0.032	0.135	0.315	0.559	0.847	1.162	1.486	1.808
2023	0.034	0.137	0.311	0.540	0.808	1.096	1.390	1.679
2024	0.037	0.145	0.322	0.553	0.819	1.104	1.393	1.677
2025	0.033	0.137	0.316	0.559	0.845	1.156	1.477	1.794

The most pronounced decreases in parameter  $b$  partially coincided with periods associated with warm El Niño–Southern Oscillation (ENSO) events (1982–1983, 1997–1998, and 2015–2016), during which the weakening of coastal upwelling and the reduction in primary productivity alter food availability. This results in poorer body condition, reflected in lower somatic biomass accumulation relative to growth in length.

From a methodological perspective, these results have direct implications for biomass estimation and stock assessment. The use of constant L–W relationships, a common practice in fisheries models (SPARRE & VENEMA, 1998), could introduce significant biases, especially in long-term series or highly variable ecosystems. Given the exponential nature of this relationship, even small variations in  $b$  may generate substantial differences in biomass estimates, leading to over- or underestimation.

The robustness of the results is supported by the extensive temporal coverage and large sample size, which allow an adequate representation of the biological and environmental variability of the stock. Likewise, weight-at-age estimates showed a consistent pattern of increasing weight with age, although interannual variations highlighted the influence of environmental conditions on individual growth.

Overall, the results suggest the need to incorporate dynamic or temporally stratified parameterization schemes into fisheries assessment models. This approach would allow a more realistic representation of the biological variability of the stock and reduce uncertainty in population estimates (CARVALHO *et al.*, 2021). In this context, the use of L–W relationships should be restricted to the ranges and conditions for which they were estimated, avoiding extrapolations that may compromise model robustness.

## 5. CONCLUSIONS

- The length–weight relationship of jack mackerel showed a high level of statistical fit and exhibited an allometric growth pattern.
- The allometric parameter  $b$  showed marked temporal variability during the 1971–2025 period, suggesting the influence of environmental and biological factors associated with the Humboldt Current System.
- Decreases in parameter  $b$  partially coincided with warm El Niño–Southern Oscillation (ENSO) events, indicating possible effects of oceanographic variability on the body condition and growth of the stock.
- Weight-at-age estimates showed a progressive increase in body weight as fish age increased, although interannual fluctuations attributable to environmental and trophic changes were observed.
- The use of constant parameters in the length–weight relationship could introduce biases in biomass estimation and stock assessment; therefore, the incorporation of dynamic parameterization schemes in fisheries models applied to jack mackerel is recommended.

## 6. ACKNOWLEDGEMENTS

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