Research Article/Mechanical Engineering, Mechatronics, and Materials Science http://doi.org/10.15446/ing.investig.116364

Effect of Ship Size on the Hull Dimension Ratios of Purse Seiners

Efecto del tamaño de la embarcación sobre los coeficientes de dimensiones del casco de los barcos cerqueros

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ABSTRACT

In the preliminary ship design stage, the first approximations of speed, stability, structure, weight, and cost, among others, are reached by selecting the appropriate hull dimension ratios. This research was motivated by the noticeable lack of systematic data on these ratios in the literature on American-type semi-industrial purse seiners. Regression analysis was performed to investigate the relationship between hull dimension ratios and vessel size from a database composed of 130 purse seiners of the Peruvian fleet. This work aimed to determine the effect of vessel size, as characterized by length, breadth, depth, gross tonnage, net tonnage, and fish hold capacity, on the main hull dimension ratios of purse seiners, *i.e.*, length/breadth, length/depth, and breadth/depth. A compilation of hull statistics for the ship attributes and ratios was elaborated, with the findings indicating that length significantly affects the slimness of American-type semi-industrial purse seiners, whose structural strength and ship weight increase with length. These vessels exhibit an invariable minimum stability according to standard criteria since a breadth-to-depth ratio of 2 is maintained. In this vein, depth is half the value of breadth. The other parameters do not affect the hull dimension ratios. The estimated regression equations and the patterns presented in this research can be used in the preliminary design stage of American-type semi-industrial purse seiners.

Keywords: hull dimension ratios, purse seiner, ship size, regression analysis, hull statistics

RESUMEN

En la etapa preliminar de diseño de barcos, se alcanzan las primeras aproximaciones de velocidad, estabilidad, estructura, peso y costo, entre otros, mediante la selección de proporciones adecuadas para las dimensiones del casco. Esta investigación fue motivada por la notable falta de datos sistemáticos sobre estas proporciones en la literatura sobre los cerqueros semi-industriales de tipo americano. Se realizó un análisis de regresión para investigar la relación entre las proporciones de las dimensiones del casco y el tamaño del barco a partir de una base de datos compuesta por 130 cerqueros de la flota peruana. El objetivo de este trabajo fue determinar el efecto del tamaño del barco, caracterizado por su eslora, manga, profundidad, tonelaje bruto, tonelaje neto y capacidad de bodega de pescado, sobre las principales proporciones de las dimensiones del casco de los cerqueros, *i.e.*, eslora/manga, eslora/profundidad y manga/profundidad. Se elaboró una recopilación de estadísticas del casco para los atributos y proporciones del barco, y los resultados indican que la eslora afecta significativamente la delgadez de los cerqueros semi-industriales de tipo americano, cuya resistencia estructural y peso aumentan con la eslora. Estos barcos presentan una estabilidad mínima invariable de acuerdo con los criterios estándar, pues se mantiene una proporción manga/profundidad de 2. En este sentido, la profundidad es la mitad del valor de la manga. Los otros parámetros no afectan las proporciones de las dimensiones del casco. Las ecuaciones de regresión estimadas y los patrones presentados en esta investigación pueden utilizarse en la etapa preliminar de diseño de los cerqueros semi-industriales de tipo americano.

Palabras clave: relaciones de dimensiones del casco, cerquero, tamaño del barco, análisis de regresión, estadísticas del casco

Received: August 24th, 2024
Accepted: March 3rd, 2025

Introduction

In the preliminary ship design stage, the first approximations of speed, stability, structure, weight, and cost are reached by selecting the main hull proportions, also referred to as the *hull dimension ratios*, a definition that will be adopted henceforth. Through these ratios, designers can prioritize ship qualities such as seakeeping, velocity, stability, and so on. To accomplish this task, they need an available source of updated hull dimension ratios. Recently, hull dimension ratios for the preliminary design stage have been a hot research topic, *e.g.*, in chemical tankers [1] and Grand Canal ships [2]. [3] developed and compared simple regressions with equivalent formulations available in the literature, proving the better approximations of the trends for 260 non-sister container ships. Similarly, [4] arrived at a practical formula

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to assist naval architects in the preliminary design of cruisers with regard to gross tonnage. Likewise, [5] proposed a procedure for determining the optimal characteristics of multi-purpose cargo vessels (MPCVs) in the preliminary design stage. Their procedure relies on a statistical analysis of the MPCV database.

[6] reported a length over breadth ship ratio (L/B) equal to 4 m for small crafts, which included fishing boats less than 30 m in length. Instead, for vessels 30-130 m in length, a range that covers coasters and general cargo ships, L/B varies according to the formula L/B = 0.025.L+3.25. Furthermore, for ships over 130 m in length, L/B is around 6.5. For volume carrier ships, a category that includes fishing and cargo ships whose depth is limited due to stability considerations, the breadth over depth ratio (B/D) is around 1.65 [7].

[8] obtained formulas for determining the general patterns and dependence of fishing vessel dimensions on their main design attributes. The studied fishing vessels included purse seiners, trawlers, trawlers, and seiners. These formulas were the result of statistically analyzing 1080 fishing vessels in operation with over 100 GRT and classified under the RMRS class. They relate B to L and D to L. Said formulas are $B = 0.8.L^{2/3}$ and $D = 0.2.L^{0.87}$ for vessels between 15 and 120 m in length.

[9] studied the main attributes of 2000 Chinese fishing vessels (fishing tackle vessels, trawlers, and purse seiners). They performed a regression analysis and obtained the relationships between L and other attributes. They developed formulas relating B to L and D to L, *i.e.*, B = 0.142.L+2.433; D = 0.07207.L+1.129 for vessels between 15 and 115 m.

[10] presented an estimated regression equation for fishing vessels, wherein L/B is a function of the length between perpendiculars L_{pp}: $L/B = 1.8006 \cdot \ln(L_{pp}) - 2.367$. He also presented the range L_{pp}/D: $8.2 \leq L_{pp}/D \leq 9.0$. He used the IHS Fairplay World Shipping Encyclopedia, which includes a database comprising 637 fishing vessels 20-130 m in length.

[11] considered fishing trawler hulls in their numerical method to determine the stability of fishing vessels. They presented their optimal L/B range, which varies from 4.4 to 5.8.

When designing a fishing vessel, the naval architect considers a list of requirements from the ship owner. *i.e.*, length, fish hold capacity, gross tonnage, net tonnage, speed, power, and range. The fulfilment of these requirements constitutes the preliminary design stage, where the professional usually follows a method based on a parent ship or on statistics. The statistical method is particularly useful when information on parent ship lines is unavailable. The parent ship lines of a semi-industrial purse seiner are usually based on the American or European types, as detailed in a work by the Food and Agriculture Organization (FAO) [12].

American-type purse seiners, with the bridge and accommodation forward and the working deck aft, are usually built in the eastern Pacific Ocean, *e.g.*, in the Peruvian sea. The lines of American-type purse seiners are not always accessible for conducting a systematic series analysis. Consequently, the design process must rely on statistical methods, which aim to determine how the hull dimension ratios are affected by the ship's size to predict its quality. *Ship size* may refer to any of the following characteristics: linear ship dimensions, volume, or deadweight. On the other hand, ship qualities may include speed, stability, structure, weight, seakeeping, or cost. This research was motivated by the noticeable lack of systematic data and regression models on hull dimension ratios in the literature on American-type semi-industrial purse seiners.

This work seeks to determine the influence of purse seiner size on hull dimension ratios. It analyzes the main ship size characteristics, *i.e.*, length (L), breadth (B), gross tonnage (GT), net tonnage (NT), and fish hold capacity (FHC). The hull dimension ratios analyzed herein are L/B, L/D, and B/D. This research relies on the database of fishing vessels published by the Peruvian Government's Ministry of Production (PRODUCE) [13], and it provides exhaustive information on hull statistics, regression and correlation analysis, significance tests, and the patterns revealed, which will aid in the preliminary design stage of semi-industrial purse seiners.

Methodology

Ship database

This research collected data on purse seiners from the records of the vessel registry of PRODUCE [13] for the 1996-2000 period, employing a collection of 130 typical American-type semi-industrial purse seiners with a section plan similar to that of the UCB systematic series [14]. These vessels have two knuckles on the hull and a refrigerated sea water (RSW) conservation system. Table I summarizes the characteristics of the database. Regression and correlation analyses, as well as significance tests, were conducted to investigate the effect of purse seiner size on hull dimension ratios.

Table I. Size characteristics in the purse seiner database

Main characteristic	Symbol	SI Units	Minimum	Maximum
Length	L	m	21.7	77.0
Breadth	B	m	6.0	11.6
Depth	D	m	2.60	5.73
Gross tonnage	GT	-	21.82	312.63
Net tonnage	NT	-	72.5	1006.7
Fish hold capacity	FHC	m^3	89.2	868.3

Source: Author

Regression analysis methodology

The main hull dimension ratios used in this study are L/B, L/D, and B/D, as listed in [15]. L/B represents a measure of slimness, a ratio related to ship speed. For example, "fast ships require larger length to beam [breadth] ratios than slow ships", according to [16, p. 201]. Additionally, the L/D ratio affects the structural integrity and weight of a ship [17], and B/D provides information on stability, as indicated by the inclination of the height of the center of gravity above the keel. B/D relates to the ship stability because $\overline{KM}$ is a function of B and $\overline{KG}$ is a function of D [18].

During the ship concept design stage, the operational requirements are defined in terms of engineering parameters. In the subsequent preliminary design phase, the final ship proportions, arrangements, power plant type, and structural layout are determined to meet said requirements [19]. Shipowners usually give the shipbuilder four pieces of information: the type of vessel, the deadweight, the required service speed, and the route on which the new vessel will operate [20]. Regarding the latter, a length or breadth constraint may be imposed by the dimensions of docks and canal locks. The ship's linear dimension is mainly represented by L, and the two other relevant linear dimensions are B and D.

A second measure of ship size is volume, which is characterized by GT and NT. The former represents the total enclosed volume of the ship, and the latter considers the volume of the cargo and passenger spaces. *Tonnage* was defined by the International Convention on Tonnage Measurement of Ships held in 1969 [16]. Another measure of ship size that is related to fishing vessel volume is the FHC.

The GT equation is as follows:

$$GT = K_1 V \tag{1}$$

where:

- $K_1 = 0.2 + 0.02 \cdot \log_{10} V$
- V = total volume of all enclosed spaces of the vessel in m^3

NT is a measure of the carrying capacity of a vessel. It can be regarded as an indicator of revenue-generating capacity. It is determined as a function of the molded volume of the vessel. This equation also includes the volume of the cargo space plus the volume of the passenger spaces. The NT equation is as follows:

$$NT = K_2 V_c \left(\frac{4T}{3D}\right)^2 + K_3 \left(N_1 + \frac{N_2}{10}\right) \tag{2}$$

where:

- $K_2 = 0.2 + 0.02 \cdot \log_{10} V_c$
- $K_3 = 1.25\left(\frac{GT + 10000}{10000}\right)$
- V_c = total volume of the cargo spaces in m^3
- D = molded depth amidships in m
- T = molded draught amidships in m
- N_1 = number of passengers in cabins with no more than eight berths
- N_2 = number of other passengers
- The NT value is not less than 30% of the GT.

Finally, deadweight (DWT) is the third measure of ship size. It is the weight of cargo that can be carried at full load draft. Specifically, DWT is the difference between the full load displacement weight and the lightship weight. This measure is mainly used in bulkers, container ships, tankers, and general cargo ships. For fishing vessels, FHC is used instead of DWT.

Within the simple regression methodology, the coefficient of determination was quantified and compared against the values found in the literature to assess regression accuracy. The equation for the coefficient of determination (R^2) is as follows [21]:

$$R^2 = 1 - \frac{\sum_{i=1}^{n}\left(y_i - y_i^*\right)^2}{\sum_{i=1}^{n}\left(y_i - \overline{y}\right)^2} \tag{3}$$

where y_i are n observations, y_i^* represents the predicted values, and $\overline{y}$ is the mean value of the observations.

The confidence intervals for the true slope and the intercept are presented below.

$$\left.\begin{array}{l} b_1 - t_{\alpha/2} s_{b_1} \le \beta_1 \le b_1 + t_{\alpha/2} s_{b_1} \\ b_0 - t_{\alpha/2} s_{b_0} \le \beta_0 \le b_0 + t_{\alpha/2} s_{b_0} \end{array}\right\} \tag{4}$$

where s_{b_1} is the standard error of the slope, s_{b_2} is the standard error of the intercept, β_1 is the true slope, β_0 is the true intercept, and t denotes Student's t with d.f. = n-2 degrees of freedom at a 95% confidence level.

Are the true slope and intercept different from zero? The hypotheses and criteria in this regard are:

Coefficient	Hypotheses	Criteria
Slope	$H_0 : \beta_1 = 0$	
	$H_1 : \beta_1 \neq 0$	$p_{value} < 0.05$

Intercept $H_0 : \beta_0 = 0$

$H_0 : \beta_0 \neq 0 \qquad p_{value} < 0.05$

Generally, three characteristics representing the ship size are used in the database: linear dimensions, volume characteristics, and DWT. Notably, as fishing vessels are categorized as volume carriers, DWT was not used in this research. There are a few relevant hull dimension ratios (L/B, L/D, B/D) and other measures related to immersion depth. However, as the database does not include information on the latter, only L/B, L/D, and B/D were considered.

Results and discussion

Hull statistics

This subsection discusses central tendency, dispersion, and distribution shape. In statistics, the central tendency of the data is represented by the mean or the median (when the data are continuous). Table II shows that the mean and median are markedly different for GT, which was quantified using Eq. (1); NT, which was quantified using Eq. (2); and FHC, as obtained from measurements. Therefore, using the mean or median to determine the central tendency of variables relies on the distribution shape or on skewness and kurtosis.

In our case, the skewness for all variables exceeds 0.5, except for L, B, D, and L/B. The kurtosis is higher than 0.5, except for B, so the median represents the central tendency of all variables except B. Their distribution shape denotes right skewness, and the frequency is higher than expected. B is the only variable with a normal distribution, so its mean represents its central tendency.

Although the median and mean of B/D are the same and equal to two, the distribution of B/D is non-normal. In general terms, we can say that the value of D is taken as half of B. Standard deviation and range values were used to set the number of bins in the corresponding histograms.

Fig. 1 shows the distribution of L as representative of the linear dimension variables. This distribution exhibits a long tail to the right and a concentration between 40 and 48 m in length. Fig. 2 suggests that 70% of American-type semi-industrial purse seiners in the Peruvian fleet are about over 300 GT, and about 42% of vessels are over 400. The GT distribution is skewed right and concentrated between 300 and 500 GT.

The FHC distribution does not follow a normal distribution (Fig. 3). Roughly five vessels have extreme FHCs, *i.e.*, over 700 m^3. The FHC ranges from 400 to 700 m^3. High positive values regarding skewness, kurtosis, and the variation in the histograms indicate that the variables (except B) do not have a normal distribution. In light of the above, the median was selected as the best measure of central tendency for the Peruvian fleet of American-type semi-industrial purse seiners. This fleet is composed of vessels with a length of about 33 to 55 m, about 300 to 500 GT, and about 300 to 500 m^3 of FHC.

The histograms reveal an upper L limit of 70 m instead of 77 m, as initially shown in Table I. Vessels over 70 m in length belong to a new category of ships, with a GT over 600, a NT over 175, and a FHC over 600 m^3. The existence of large fishing vessels in the Peruvian fleet may be due to the need for catching larger species than anchovy, like tuna, in order to preserve the catch for more time using advanced processing facilities, improve energy use, and sail out to sea and stay there longer.

The hull statistics of the Peruvian fishing fleet resemble those of other fleets from the west coast of the American continent because anchovy and other small species are mainly caught using American-type purse seiners. Thus, the results provide meaningful information for the preliminary stage of fishing vessel design.

Table II. Descriptive statistics of ship size for the Peruvian fleet (American-type semi-industrial purse seiners)

Statistic	*Length (m)*	*Breadth (m)*	*Depth (m)*	*L/B*	*L/D*	*B/D*	*Net tonnage*	*Gross tonnage*	*Fish hold capacity (m^3)*
Mean	**43.5**	**9.0**	**4.4**	**4.81**	**9.73**	**2.02**	**113.7**	**376.5**	**446.3**
Standard error	0.8	0.1	0.1	0.06	0.12	0.01	3.6	14.5	12.3
Median	**43.3**	**8.9**	**4.4**	**4.70**	**9.42**	**2.00**	**110.5**	**366.5**	**440.0**
Standard Deviation	**8.7**	**1.1**	**0.6**	**0.63**	**1.34**	**0.14**	**41.4**	**164.7**	**140.5**
Kurtosis	**1.6**	**-0.3**	**0.9**	**1.37**	**2.51**	**10.91**	**4.2**	**1.6**	**1.5**
Skewness	**0.2**	**-0.01**	**-0.4**	**0.42**	**1.01**	**2.37**	**0.9**	**0.8**	**0.1**
Range	52.3	6.6	3.1	3.88	9.25	1.14	290.8	934.2	779.0

Source: Author

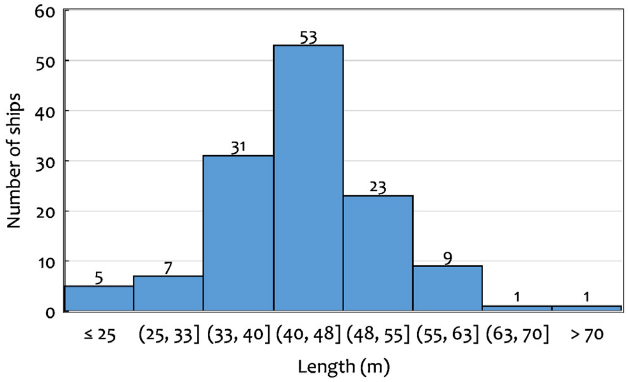

Figure 1. Length histogram for the American-type semi-industrial purse seiners in the Peruvian fleet
Source: Author

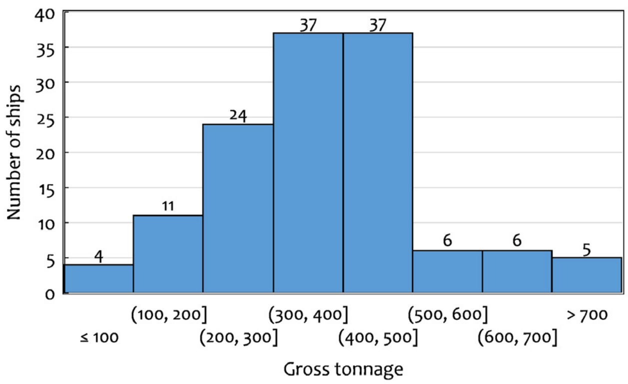

Figure 2. Gross tonnage histogram for the American-type semi-industrial purse seiners in the Peruvian fleet
Source: Author

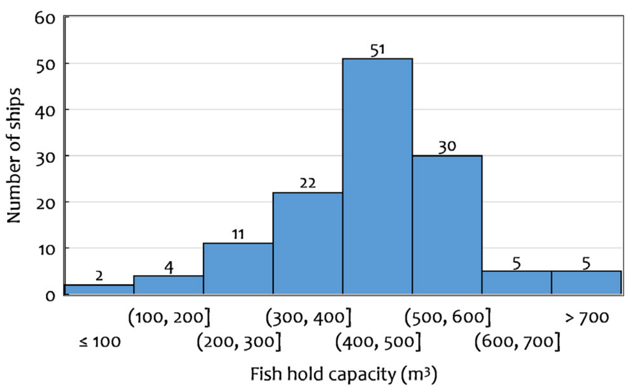

Figure 3. Fish hold capacity histogram for the American-type semi-industrial purse seiners in the Peruvian fleet
Source: Author

Regression analysis

In the model, the response variables are L/B, L/D, and B/D. In addition, the predictor variables are L, B, D, GT, NT, and FHC. Table III presents the estimated slope b_1 and the intercept b_0, as well as the R^2 for all combinations of the response and predictor variables. The table shows that a straight line does not fit the data of the response and predictor variables, except for the combinations between L/B and L and L/D and L. Since the L/B regression yields an R^2 value of 0.66, we could say that L explains 66% of the variation in L/B. Similarly, L explains 67% of the L/D variation because the regression yields an R^2 of 0.67.

The unexplained variation reflects factors not included in our model (*e.g.*, later elongations, intact stability criteria, seakeeping qualities, and speed and power considerations) or just plain random variation. In this case, there is, in theory, a reason to believe that causation exists; specifically, increased length increases the slimness of the vessel, as well as the structural integrity and weight of a ship. The estimated regression equation of L/B as a function of L is:

$$\frac{L}{B} = 2,25 + 0,06 \cdot L \tag{5}$$

Each extra meter of L will add an average of 0.06 units to L/B. The intercept alone is not significant because no vessel can have L = 0 m.

The estimated regression equation of L/D as a function of L is:

$$\frac{L}{D} = 4,28 + 0,13 \cdot L \tag{6}$$

The L/D value is at least 4.28. An extra meter of L will increase L/D by 0.13 units.

The fit between the other combinations of response and predictor variables is poor, as indicated by R^2 values close to zero. Consequently, there are no useful regression equations for the remaining combinations. However, naval architects can use the mean or median while considering the hull statistics discussed in the previous section.

Fig. 4 indicates a strong positive relationship between L/B and L. A straight line can be constructed to fit the data. Many points are scattered when L ranges between 33 and 55 m, so the R^2 decreases to 0.66. Fig. 5 shows a strong positive relationship between L/D and L. The data are scattered and uniformly spread around the line.

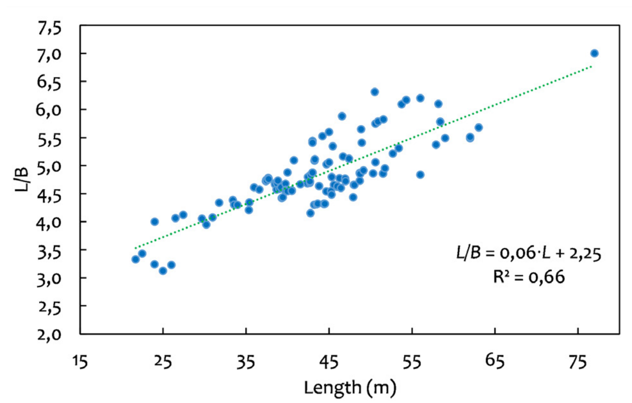

Figure 4. Regression analysis of L/B as a function of L for the American-type semi-industrial purse seiners in the Peruvian fleet
Source: Author

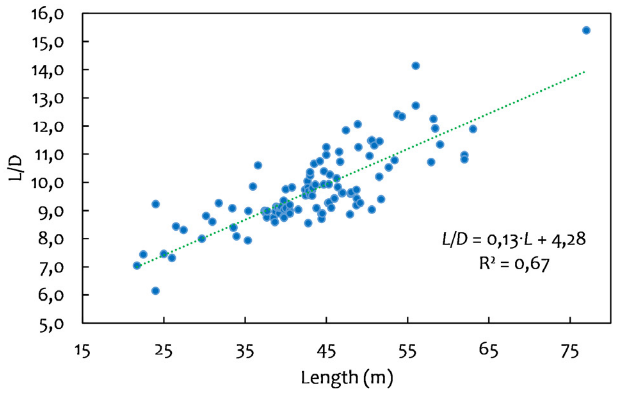

Figure 5. Regression analysis of L/D as a function of L for the American-type semi-industrial purse seiners in the Peruvian fleet
Source: Author

The scatter plot of B/D and L (Fig. 6) shows no linear relationship. The values of B/D range from 1.75 to 2.25 regardless of L. The spread of the data indicates no correlation between the variables, which is also confirmed by the low R^2 of the obtained linear trend line.

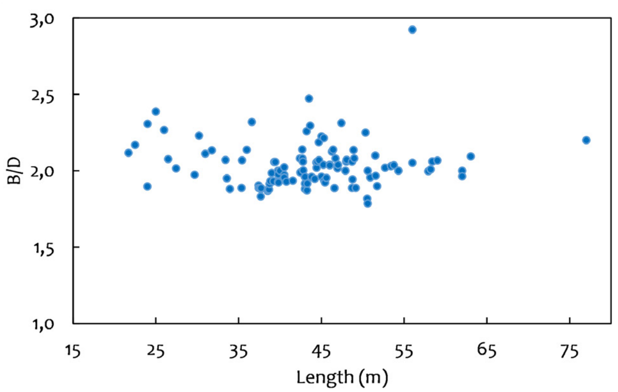

Figure 6. Scatter plot of B/D and L for the American-type semi-industrial purse seiners in the Peruvian fleet
Source: Author

The confidence intervals for the true slope and intercept can be considered trustworthy given the normality in the residuals histogram. The residuals normal probability plots of L/B and L/D exhibit $R^2 = 0.844$ for L/B *vs.* L, and 0.834 for L/D *vs.* L, thus confirming residuals normality.

The confidence intervals for the coefficients, as described in Eq. (4), are not widened because there is no heteroscedasticity in the residuals *vs.* L plot. The residuals plot does not show a left-to-right pattern.

The model's fit is not overstated because there is no pattern of non-independent errors. The Durbin-Watson statistics were nearly 2, *i.e.*, 1.62 for L/B *vs.* L, and 1.59 for L/D *vs.* L. For the two well-fitted equations (L/B *vs.* L and L/D *vs.* L), nonlinearity studies were conducted. The linear model was identified as the best fit for L/B vs. L since the coefficient of the quadratic term did not significantly differ from zero.

Similarly, for L/D *vs.* L, the linear model was deemed optimal, even though the coefficient of the quadratic term was not significantly different from zero. This decision was supported by a marginal increase in R^2: from 0.666 (linear) to 0.679 (quadratic), representing a mere 2% improvement. Introducing a squared predictor increases model complexity and reduces the number of degrees of freedom for significance testing, which justifies the preference for the simpler linear model.

According to the results, as L increases in the database, ship slimness and weight increase, and structural integrity demands more stiffness. Conversely, ship stability, represented by B/D, remains invariable. The regression analyses of the remaining variable combinations evidenced no correlations.

Table IV shows that the confidence intervals for β_1 and β_2 do not include zero for the combinations between L/B and L and L/D and L. The true slope and the intercept are nonzero for the corresponding equations, as indicated by their low p-values (≈ 0), according to Eq. (4). These nonzero values are not due to chance. Namely, the relationships between L/B and L and L/D and L are statistically significant; L/B and L/D can be predicted by L.

Although the confidence intervals show that the true slope and the intercept of the other variable combinations are

Table III. Regression analysis of the coefficients for the hull dimension ratios of the American-type semi-industrial purse seiners in the Peruvian fleet

	L/B			L/D			B/D		
	Slope (b_1)	*Intercept* (b_0)	R^2	*Slope* (b_1)	*Intercept* (b_0)	R^2	*Slope* (b_1)	*Intercept* (b_0)	R^2
Length (m)	0.06	2.25	0.66	0.13	4.28	0.66	0.00	2.00	0.00
Breadth (m)	0.17	3.29	0.09	0.51	5.13	0.18	0.03	1.75	0.05
Depth (m)	0.45	2.80	0.15	0.59	7.08	0.06	-0.08	2.38	0.09
Net tonnage	0.00	4.05	0.19	0.01	8.19	0.16	0.00	2.04	0.00
Gross tonnage	0.00	3.92	0.36	0.00	7.76	0.41	0.00	2.00	0.00
Fish hold capacity (m^3)	0.00	3.84	0.23	0.00	7.80	0.21	0.00	2.05	0.00

Source: Author

Table IV. Confidence intervals for the true slope and intercept, and p-values for the significance tests

		L/B			L/D			B/D		
		95% lower	*95% upper*	*p-value*	*95% lower*	*95% upper*	*p-value*	*95% lower*	*95% upper*	*p-value*
Length (m)	β_0	2.27	2.93	0.00	4.78	6.66	0.00	2.02	2.28	0.00
	β_1	0.04	0.06	0.00	0.07	0.11	0.00	-0.01	0.00	0.02
Breadth (m)	β_0	3.21	4.61	0.00	7.04	10.29	0.00	2.04	2.41	0.00
	β_1	0.03	0.18	0.01	-0.06	0.28	0.21	-0.04	0.00	0.02
Depth (m)	β_0	3.72	4.75	0.00	9.63	12.00	0.00	2.40	2.62	0.00
	β_1	0.02	0.24	0.02	-0.49	0.00	0.05	-0.13	-0.08	0.00
Net tonnage	β_0	4.47	4.84	0.00	9.41	10.27	0.00	2.07	2.16	0.00
	β_1	0.00	0.00	0.02	0.00	0.00	0.37	0.00	0.00	0.00
Gross tonnage	β_0	4.37	4.72	0.00	9.12	9.97	0.00	2.06	2.15	0.00
	β_1	0.00	0.00	0.00	0.00	0.00	0.43	0.00	0.00	0.00
Fish hold c. (m^3)	β_0	4.43	4.82	0.00	9.37	10.28	0.00	2.08	2.17	0.00
	β_1	0.00	0.00	0.01	0.00	0.00	0.46	0.00	0.00	0.00

Source: Author

Table V. Comparison of the obtained regression formulas against those reported in the literature

This database	**[7]**	**[10]**	**[8]**	**[9]**
L/B=0.06.L+2.25	L/B= 0.025.L+3.25	L/B=1.8006·ln(L_{pp})-2.367	L/B=1.25.$L^{1/3}$	L/B=L/(0.142.L+2.433)
B/D=2	B/D=1.65	---	---	---
L/D=0.13.L+4.28	---	8.6 in average	L/D=5.$L^{0,13}$	L/D=L/(0.07207.L+1.129)

Source: Author

significantly different from zero, the response variables could not be predicted by their corresponding predictor variables because their R^2 is nearly zero. Thereupon, the best prediction for B/D is the median, *i.e.*, the mean should not be used to predict B/D since its distribution is non-normal.

The median and mean of B/D are 2.0, which is higher than the value obtained by [10] (1.65), although this previous study does not specify the type of fishing vessel analyzed. The B/D value of 2 can be considered as a unique characteristic of American-type purse seiners.

Comparison against previous studies

Tables V and VI and Figs. 7 and 8 compare the estimated regression formulas for the analyzed database against those reported in the literature. To evaluate the goodness of fit of said formulas, their R^2 value was calculated using Eq. (3). The R^2 formula considered the database as the observed values and the predictions as the estimated values. Table VI presents the calculated R^2 for the hull dimension ratios as a function of L. Additionally, Table VI shows that only the formulas developed by [9] exhibit a certain degree of goodness of fit for the analyzed database. It is important to recall that these formulas only apply to purse seiners.

Table VI. Comparison of the R^2 obtained against the values reported in the literature

R^2	**L/B=f(L)**	**B/D=f(L)**	**L/D=f(L)**
This database	*0.66*	*0*	*0.67*
[7]	*0*	*0*	---
[10]	*0*	---	---
[8]	*0.06*	---	*0*
[9]	***0.45***	**---**	***0.40***

Source: Author

Fig. 7 compares this work's regression formula against four other regressions for L/B estimation. These estimations follow two different tendencies for L values lower than 35 m and greater than 55 m, which is only the case for the formula of [9]. The other regression formulas do not predict the L/B values of the database analyzed in this work. Fig. 8 shows that only the formula of [9] predicts the L/D values when L is between 35 and 55 m. These figures illustrate that the estimated slope and intercept of L/D as a function of L are twice the values for L/B as a function of L. This is expected because B/D = 2 for the studied database.

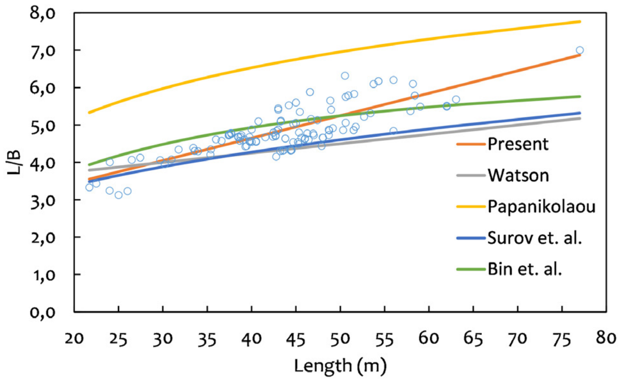

Figure 7. Length-to-breadth ratio regression compared to the reports by [7], [10], [8], and [9]
Source: Author

The regression results contrast those in [9] when L is around 55 m or higher, which could be due to the fact that fishing vessels can be elongated, keeping the master frame intact to enlarge the FHC and increase their speed. This type of hull modification is a common practice in the fishing fleets of the American Pacific coasts.

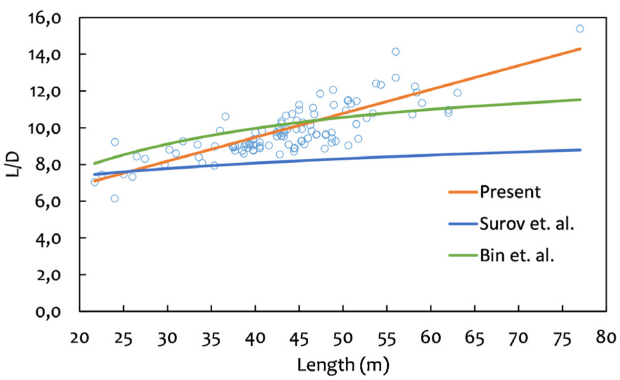

Figure 8. Length-to depth-ratio regression compared to the reports by [7], [10], [8], and [9]
Source: Author

Application example

B can be obtained from Eq. (5) if L is known. Then, D is obtained by dividing B by the B/D median (=2). Ship attributes like GT, NT, and FHC can be estimated through their corresponding median.

For example, if L = 50 m, L/B is 5.25 (L/B = 2.25+0.06.50 = 5.25). Afterwards, B is obtained by dividing L by 5.25, or B = L /5.25 = 50 / 5.25 ≈ 9.5 m. Next, D is quantified by dividing B by 2, *i.e.*, D = B / 2 = 9.5 / 2 = 4.75, or D is obtained via Eq. (6) (L/D = 4.28+0.13.L). Then, D is 4.63 m. In this vein, the GT can be roughly estimated as 366.5, the NT as 110.5, and the FHC as 440 m^3.

Conclusions

Length significantly affects the slimness of a ship. Increasing values of L increase L/B, as per the estimated regression equation L/B = 2.25+0.06.L. A straight line can be drawn in the scatter plot of L/B and L with a good fit. The confidence intervals of the true slope and intercept do not include zero. The true slope and intercept are nonzero, as indicated by their low p-values. Since L/B (ship slimness) is directly related to speed, the positive correlation between L/B and L suggests that designers may have prioritized speed over other vessel qualities when determining the hull dimensions analyzed in this work. It should be considered that, as L increases, the designer must enhance structural strength to counteract the greater bending stresses, which yields an increase in the ship's overall weight. In this vein, it is consistent that length significantly affects the L/D ratio, as per the formula L/D = 4.28+0.13.L.

In summary, the estimated regression equations for L/B and L/D as a function of length, along with the constant B/D, suggest that longer ships tend to be slimmer, prioritizing speed and stability. When B is predicted using the L/B equation, D can be estimated as half of B – statistically, the former is twice the latter. This proportion reflects the designer's focus on ensuring good stability, as B influences the metacentric height while D denotes the height of the center of gravity. For American-type semi-industrial purse seiners, this proportion remains statistically constant, prioritizing a high metacentric height over the height of the center of gravity. These vessels are consistently designed to maximize speed and ensure stability, often at the expense of other qualities.

On the other hand, B, D, GT, NT, and FHC do not affect the hull dimension ratios L/B, L/D, and B/D. This affirmation does not exclude the impact of said parameters on the ship concept design stage. This means that the hull dimension ratios are determined independently by the aforementioned variables.

A new category of ships has emerged given the need to catch species larger than anchovies, *e.g.*, tuna. The histograms and scatter plots presented in this work reveal an upper limit to the validity of the regression equations. For fishing vessels between 20 and 70 m in length, the equations hold true. For vessels exceeding 70 m, a different regression equation, tailored to a distinct ship category, would be required. These larger ships have a GT over 700 and a FHC over 700 m^3. They allow for more time spent on fishing, improve energy use, and allow sailing out to sea and staying there longer. This new category scattered the data points, resulting in low R^2 values.

Future research must be conducted to investigate the relationship between hull form coefficients, ship linear dimensions, and hull dimension ratios. Furthermore, a new concept design for an industrial purse seiner could be elaborated while considering the information presented herein.

Acknowledgements

The author would like to thank the reviewers for their comments, which helped to improve the manuscript; as well as the Vice-Principal for Research of Universidad Nacional de Ingeniería for the financial support provided under Rectoral Resolution N.º 0892-2024-UNI.

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