# Biometry of the invasive lionfish (*Pterois volitans*) in Playa del Carmen, Mexico and a review of length - weight parameters across the invasion range

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**Running title:** Length - weight parameters for *Pterois volitans*

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**Title of the contribution:** Biometry of the invasive lionfish (*Pterois volitans*) in Playa del Carmen, Mexico and a review of length - weight parameters across the invasion range

## Abstract

300 words

## Key words

lionfish, biometry, length-weight relationship, Mexico

## Resumen

300 palabras

## Palabras clave

pez león, biometría, relación lopngitud-peso, México

# Introduction

At least 84% of the marine eco-regions have reported the presence of an invasive species (Molnar et al. 2008). The presence of invasive alien species represents a major threat to local biodiversity and the economic activities that depend on it, like tourism or fisheries (Bax et al. 2003). By 2005, the economic cost of invasive species to the United States was estimated at $120 billion per year and nearly 42% of species that have been included in the Endangered or Threatened species list have been labeled as such due to presence of invasive species (Pimentel, Zuniga, and Morrison 2005). Invasive species may threaten native species through competition (Davis 2003) or predation. This highlightes the importance of understanding, managing, and preventing ecological invasions.

Lionfish (*Pterois volitans - miles* complex) are an invasive species in the North-Western Atlantic and the Caribbean likely introduced through libreation of aquarium-kept organisms (Betancur-R et al. 2011). They are the first marine vertebrates to establish in North Atlantic (Schofield 2009: Schofield (2010)) and Caribbean coasts. Lionfish have been recorded in coral reefs (Aguilar-Perera and Tuz-Sulub 2010), but also in other habitats like estuaries (Jud et al. 2011), mangroves (Barbour et al. 2010) and hard-bottom reefs (Muñoz, Currin, and Whitfield 2011). Their presence in these waters has been labeled as a major marine invasion due to its threat to local biodiversity, the veolocity of its invasion, and its difficulty of management (Hixon et al. 2016).

As ways to reduce the abundance of this invasive species local authorities have promoted removal programs incentivized consumption of this invasive species (Chin, Aiken, and Buddo 2016). Lionfish removals have shown to significantly reduce -but not quite eliminate- lionfish abundances at local scales (Sandel et al. 2015, Chin, Aiken, and Buddo (2016), de Leon et al. (2013)). While complete erradication through fishing effort is unlikely to be a solution due to the rapid recovery rates exhibited by the species (Barbour et al. 2011), further incentivizing its consumption might create a market demand big enough to promote a fishery (Chin, Aiken, and Buddo 2016).

A significant amount of research has been done on lionfish feeding ecology in North Carolina (Muñoz, Currin, and Whitfield 2011), the Bahamas (Morris and Akins 2009; Cote et al. 2013), Northern Gulf of Mexico (Dahl and Patterson 2014), Mexican Caribbean (Valdez-Moreno et al. 2012; Villaseñor-Derbez and Herrera-Pérez 2014), and Costa Rica (Sandel et al. 2015). It has been identified that lionfish can reduce recruitment (Albins and Hixon 2008) and population sizes (Green et al. 2012) of native reef-fish species, and further the endangerement of critically endangered reef fish (Rocha et al. 2015). This information has been useful in predicting the trophic impacts of lionfish (Arias-Gonzalez et al. 2011). Significant efforts have also been made to understand the possible impacts of the invasion by keeping track of the invasion range through time (Schofield 2009; Schofield 2010) and predicting invasion ranges under climate change scenarios (Grieve, Curchitser, and Rykaczewski (2016)).

Biomass is a standard indicator used to measure the state or size of a population. Biomass has been used in lionfish research to convert individual fish length observations into fish weight. In order to do this, researchers must find growth parameters thad describe the growth of their species for a particular region or location. Having precision of these parameters is important, because small changes in any of them can result in important over- or underestimation of biomass levels. This becomes particularly important when research involves, for example, identifying the total biomass available for harvest by fishers -as invasion management programs- or the efficacy of lionfish removals.

The objectives of this study include providing site-specific weight-at-length parameters for the invasive lionfish in the Mexican Caribbean region. At the same time, we highlight the importance of using site-specific parameters by estimating biomass with parameters from other regions across the invasion range and comparing them to observed biomasses. Finally, we summarize other weight-at-length studies presented, making them readily accessible for future research.

# Materials and Methods

## Area of study

The present study took place off the coasts of Playa del Carmen, in the coasts of the Mexican Caribbean. The region represents the northernmost section of the Mesoamerican reef, which extends from coast of Cancun south to Honduras (**reference**). Coral reefs and mangroves are important habitats distributed along the cost, and represent important sources of income in terms of extractive (*e.g.* recreational fishing) and non-extractive (*e.g.* SCUBA diving) activities related to tourism (**reference**), the main source of income to the local economy.

Coral reefs in the region are characterized by X, Y, Z. Descripcion general de los arrecifes.

## Fish sampling

The present study used samples obtained by Villaseñor-Derbez and Herrera-Pérez (2014) for stomach content analysis between May and August of 2010. A total of 33 SCUBA immersions were performed in 10 sampling sites along 14 Km of coast between Puerto Aventuras and Akumal (Fig. 1, Table 1). Sampling locations included wall and carpet reefs at depths between 5.7 m and 38.1 m. All observed organisms (n = 109) were collected using hand nets -to avoid weight loss due to bleeding- and numbered collection bottles. Information on depth and other comments were recorded in an underwater slide. Depth was recorded by dive gauges held by divers as safety procedures during the collections. Samples were frozen within 30 minutes of completing the dive and stored for posterior analysis in the lab. For every organism, Total Length (TL; mm) and Total Weight (TW; gr) were recorded in the lab.

## Data analysis

The weight at length relationship between the observed variables was calculated with the allometric growth function:

$$TW = aTL^b \tag{1}$$

Where $TW$ is the Total Weight (gr), $TL$ is the observed Total Length (mm), $a$ is the ponderal index and $b$ is the scaling exponent or allometric parameter. When $b = 3$, it is said that the organism exhibits a perfect isometric growth. The dependent and independent variables were transformed via base-10 logarithms so that the equation is then:

$$log_{10}(TW) = blog_{10}TL + log10(a) \tag{2}$$

To simplify this equation, we can re-write it as:

$$Y = mX + c \tag{3}$$

Where $Y = log_{10}(TW)$, $X = log_{10}(TL)$, $m = b$, and $c = log_{10}(a)$. The coefficients ($c$ and $b$) were estimated with an Ordinary Least Square Regression and heteroskedastic-robust standard errors. Both coefficients were tested agains the null hypothesis of no change (*i.e.* $h_0 : c = 0$ and $h_0 : b = 0$). Additionally, the allometric parameter was tested against the null hypothesis of isometric growth ($H_0 : b = 3$). Coefficient testing was made with a two-tailed Student's t-test. The significance of the regression was corroborated with an F-test.

Other growth parameters were extracted from published research from North Carolina (Barbour et al. 2011), Northern (Fogg et al. 2013) and Southern (Aguilar-Perera and Quijano-Puerto 2016) Gulf of Mexico, the Southern Mexican Caribbean (Sabido-Itza et al. 2016), Little Cayman (Edwards, Frazer, and Jacoby 2014), Jamaica (Chin, Aiken, and Buddo 2016), Bonaire (de Leon et al. 2013) and Costa Rica (Sandel et al. 2015). Additionally, parameters from Fishbase (Froese and Pauly 2016) were also included in this study. When available, information on sampling methods, location, and depth ranges of each study was retreived. During this review process, it was noticed that some papers indistinctly use $a$ to report either the ponderal index in **eq. 1** or the y-intercept ($c$) in **eq. 2**, which might sometimes be overlooked. Furthermore, some studies report their parameters as mm-to-gr conversions, but a rapid evaluation of such parameters indicates that they were estimated as cm-to-gr conversions. Here, both parameters ($a$ and $c$) are reported for the present findings and, when ever required, values from other studies are converted for consistency. All coefficients are reported as mm to gr conversions.

Observed biomass was calculated as the sum of all observed organisms for each location. Expected biomass for each organism was calculated with the growth parameteres estimated in this study, as well as those retreived from additional literature. Then, total expected biomass was calculated for each surveyed site as the sum of expected biomasses previously calculated. For each study and site, biomass was divided by the corresponding observed biomass to obtain a ratio that allowed rapid identification of over- or underestimation. Therefore, values lower than 1 indicate that the parameters used underestimate the biomass. On the other side, values larger than 1 indicate that the parameteres used overestimate biomass. Mean expected-to-observed biomass ratios were calculated by averaging across all sites for each study.

All hypothesis testing was performed with a confidence level of $\alpha = 0.01$ and performed in R version 3.4.0 (R Core Team 2017). Data wrangling was performed with the tidyverse package (Wickham 2017). Maps were created with a mix of functions from the sp (Pebesma and Bivand 2005), rgdal (Bivand, Keitt, and Rowlingson 2017), tmap (Tennekes 2017a), and tmaptools (Tennekes 2017b) packages. Correction for heteroskedastic-robust standard errors was done with the sandwich (Zeileis 2004) and lmtest (Zeileis and Hothorn 2002) packages. Models were manipulated with with the broom package (Robinson 2017). Stargazer (Hlavac 2015) was used to produce the tables, and refmanager (McLean 2014) was used to keep track of citations. The manuscript was written in rmarkdown (Allaire et al. 2017) and processed with the knitr package (Xie 2017).

# Results

A summary of Total Lengths and Total Weights of the the 109 sampled organisms is presented in Table 1. The smallest organism (TL = 34.00) was also the lightest organism (TW = 0.30). However, the largest organism (TL = 310.00) was not the heaviest (TW = 303.70), and the heaviest organism (TW = 397.70) was 292.00 mm in total length. Kernell density plots (Fig. 2) show the distribution for TL and TW. Both measures were positively skewed, with skewness of 0.85 for TL and 2.19 for TW.

## Length-weight relationship

The model adjusted to eq. 3 estimated the coefficient values at $m = 3.2347391$ and $c = -5.4940866$. The intercept and slope were significantly different from zero ($t(107) = -66.17; p < 0.01$ and $t(107) = 83.24; p < 0.01$, respectively), rejecting the null hypothesis of no change. Additionally, the allometric factor was significantly different from zero ($t(107) = 6.04; p < 0.01$). More information on model fit and confidence intervals of estimated coefficients is presented in Table 3.

### Comparison of allometric parameters

## Discussion and Conclusions

Not using spear poles allows us to have a full sample of fish with a wider range of sizes and weights, ideal for visual census. Also, there is no loss in body mass due to bleeding.

## Aknowledgements

# Tables

## Location table

Table 1: Coordinates, minimum, maximum and mean depth (m), and number of samples for each location. n = sample size.

| Location | Lat. | Long. | Min. Depth | Max. Depth | Mean Depth | n |
|---|---|---|---|---|---|---|
| Canones | 20.477 | -87.233 | 15.0 | 31.2 | 21.6 | 11 |
| Castillo | 20.496 | -87.220 | 12.5 | 30.5 | 27.5 | 18 |
| Cuevitas | 20.478 | -87.244 | 7.4 | 12.8 | 11.2 | 4 |
| Islas | 20.490 | -87.228 | 14.0 | 19.4 | 16.7 | 10 |
| Paamul | 20.513 | -87.192 | 9.9 | 22.7 | 15.5 | 31 |
| Paraiso | 20.484 | -87.226 | 9.4 | 38.1 | 17.7 | 16 |
| Pared | 20.502 | -87.212 | 12.1 | 21.0 | 16.3 | 12 |
| Pedregal | 20.507 | -87.204 | 14.4 | 14.9 | 14.7 | 3 |
| Santos | 20.493 | -87.222 | 5.7 | 26.6 | 16.2 | 2 |
| Tzimin-Ha | 20.393 | -87.307 | 21.2 | 24.6 | 22.9 | 2 |
| Total | | | 5.7 | 38.1 | 18.6 | 109 |

## Summary table

Table 2: Summary statistics of Length and Weight of sampled organisms.

| Statistic | N | Mean | St. Dev. | Min | Max |
|---|---|---|---|---|---|
| Length | 109 | 140.22 | 62.41 | 34 | 310 |
| Weight | 109 | 52.56 | 76.58 | 0.30 | 397.70 |

# Regression table

Table 3:

| | *Dependent variable:* |
|---|---|
| | log10(Weight) |
| Constant | $-5.494$ ($-5.657$, $-5.331$)$^{***}$ |
| log10(Length) | 3.235 (3.159, 3.311)$^{***}$ |
| F Statistic | 6928.67$^{***}$ (df = 1; 107) |
| Observations | 109 |
| Adjusted $R^2$ | 0.976 |
| Residual Std. Error | 0.096 (df = 107) |
| *Note:* | $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$ |

## Review table

Table 4: Allometric growth parameters for eight published papers, Fishbase (Froese and Pauly 2016), and this study. All parameters have been adjusted to convert from millimiters to grams. n = Sample size, a = scaling parameter for eq. 1, c = y-intercept for eq. 3, b = exponent or slope for eq. 1 or eq. 2, respectively.

| Reference | n | a | c | b | r2 | Gender | minD | maxD |
|---|---|---|---|---|---|---|---|---|
| (Aguilar-Perera and Quijano-Puerto 2016) | 472 | 0 | -5.5400 | 3.3000 | 0.9500 | Both | 5.0 | 20.0 |
| (Aguilar-Perera and Quijano-Puerto 2016) | 67 | 0 | -5.9300 | 3.4700 | 0.9500 | F | 5.0 | 20.0 |
| (Aguilar-Perera and Quijano-Puerto 2016) | 59 | 0 | -5.3800 | 3.2300 | 0.9500 | M | 5.0 | 20.0 |
| (Sandel et al. 2015) | 458 | 0 | -4.4400 | 2.8100 | NA | Both | NA | NA |
| (Chin, Aiken, and Buddo 2016) | 419 | 0 | -4.5600 | 2.8500 | 0.8715 | Both | 18.3 | 18.3 |
| (Barbour et al. 2011) | 774 | 0 | -4.5391 | 2.8900 | NA | Both | 27.0 | 45.0 |
| (de Leon et al. 2013) | 1450 | 0 | -4.6411 | 2.8900 | 0.9600 | Both | NA | NA |
| (Fogg et al. 2013) | 582 | 0 | -5.8600 | 3.4349 | 0.9900 | Both | NA | NA |
| (Fogg et al. 2013) | 119 | 0 | -5.5700 | 3.3100 | 0.9700 | M | NA | NA |
| (Fogg et al. 2013) | 115 | 0 | -5.1700 | 3.1437 | 0.9400 | F | NA | NA |
| (Edwards, Frazer, and Jacoby 2014) | 1887 | 0 | -5.5229 | 3.2400 | 0.9700 | Both | 15.0 | 30.0 |
| (Sabido-Itza et al. 2016) | 2143 | 0 | -5.2828 | 3.1832 | 0.9907 | Both | 0.5 | 57.0 |
| (Froese and Pauly 2016) | NA | 0 | -5.0293 | 3.0900 | NA | Both | NA | NA |
| This study | 109 | 0 | -5.4941 | 3.2347 | 0.9766 | Both | 5.7 | 38.1 |

178 # Figures

179 ## Map

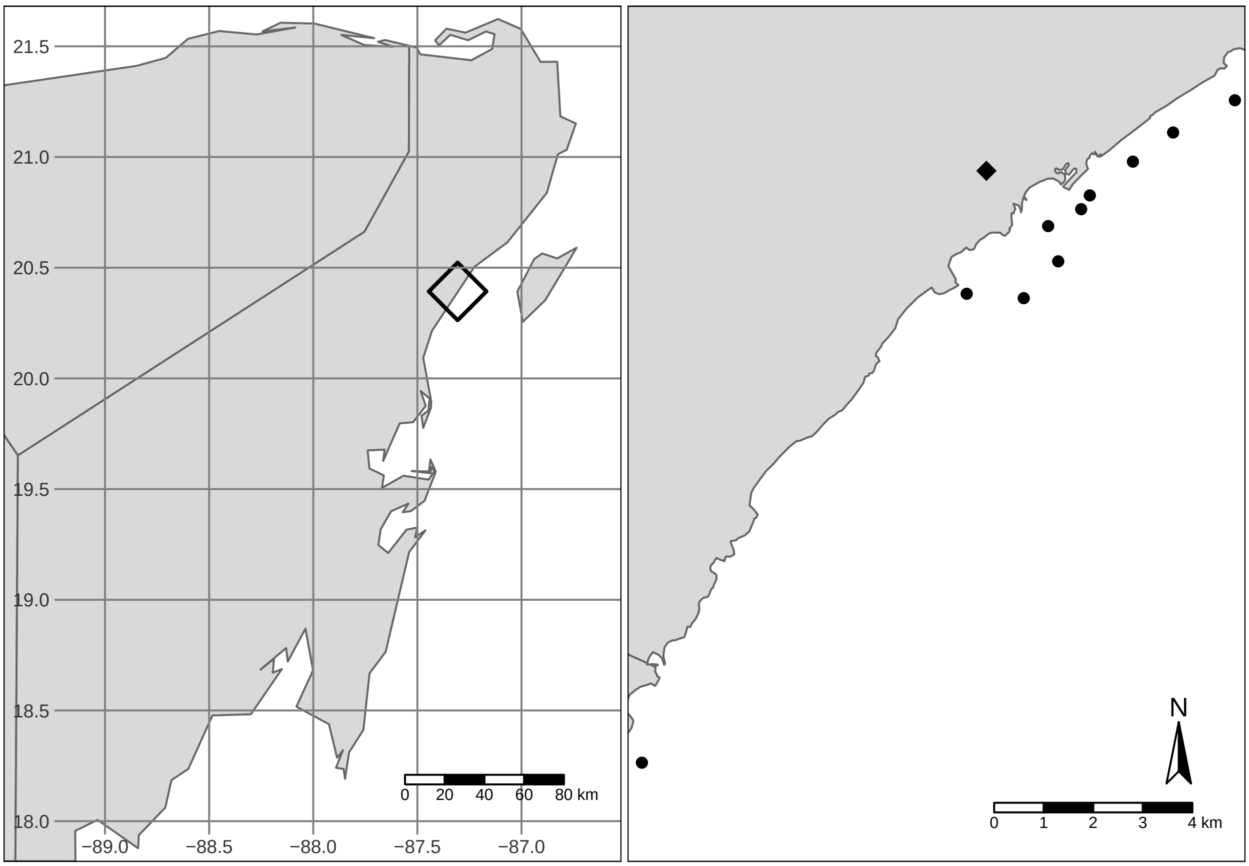


Figure 1: Map of the study area. The black inset on the left indicates the location where study sites are distributed. On the right, circular markers indicate sampling sites and the black romboid indicates location of Puerto Aventuras.

## Histograms

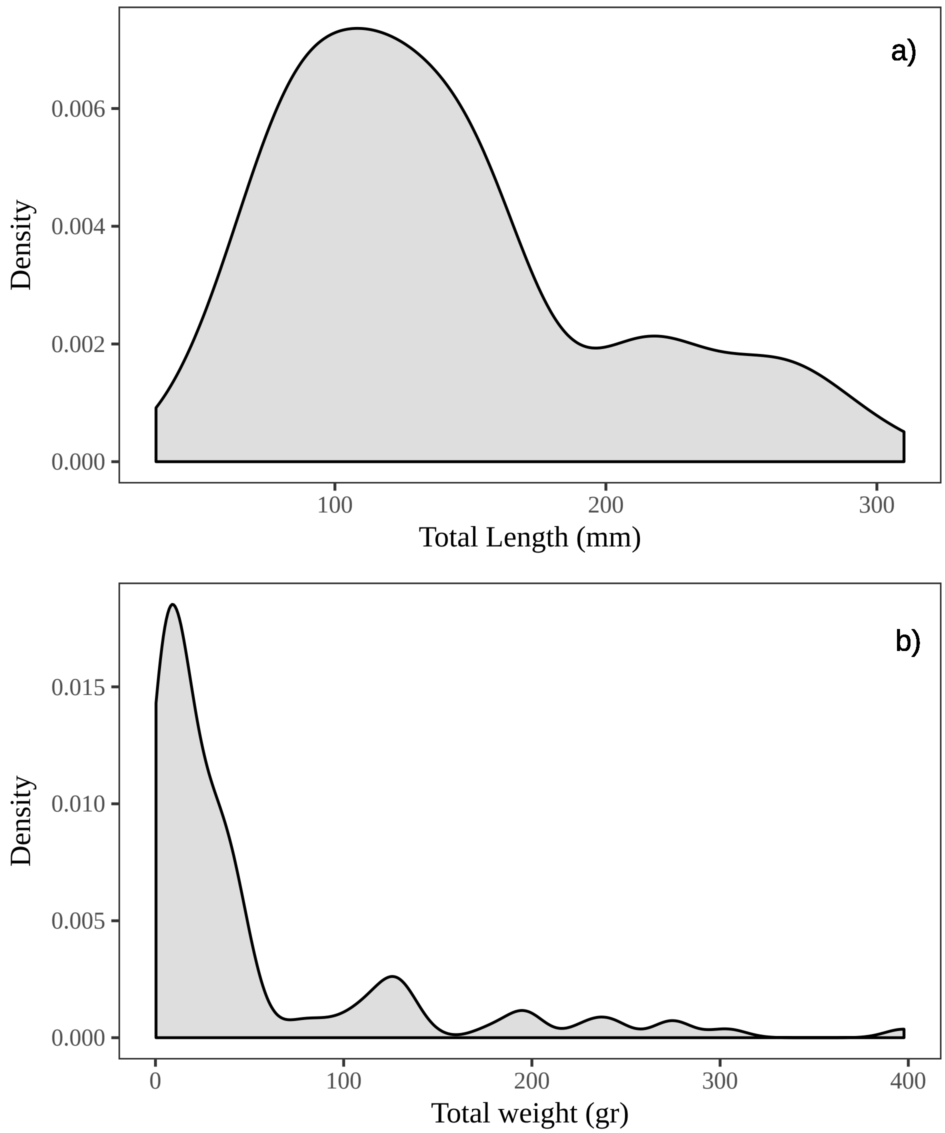


Figure 2: Kernell density plots for a) Total length (mm) and b) Total weight (gr) for 109 lionfish sampled off the coast of Puerto Aventuras, Mexico.

## Scatter plot

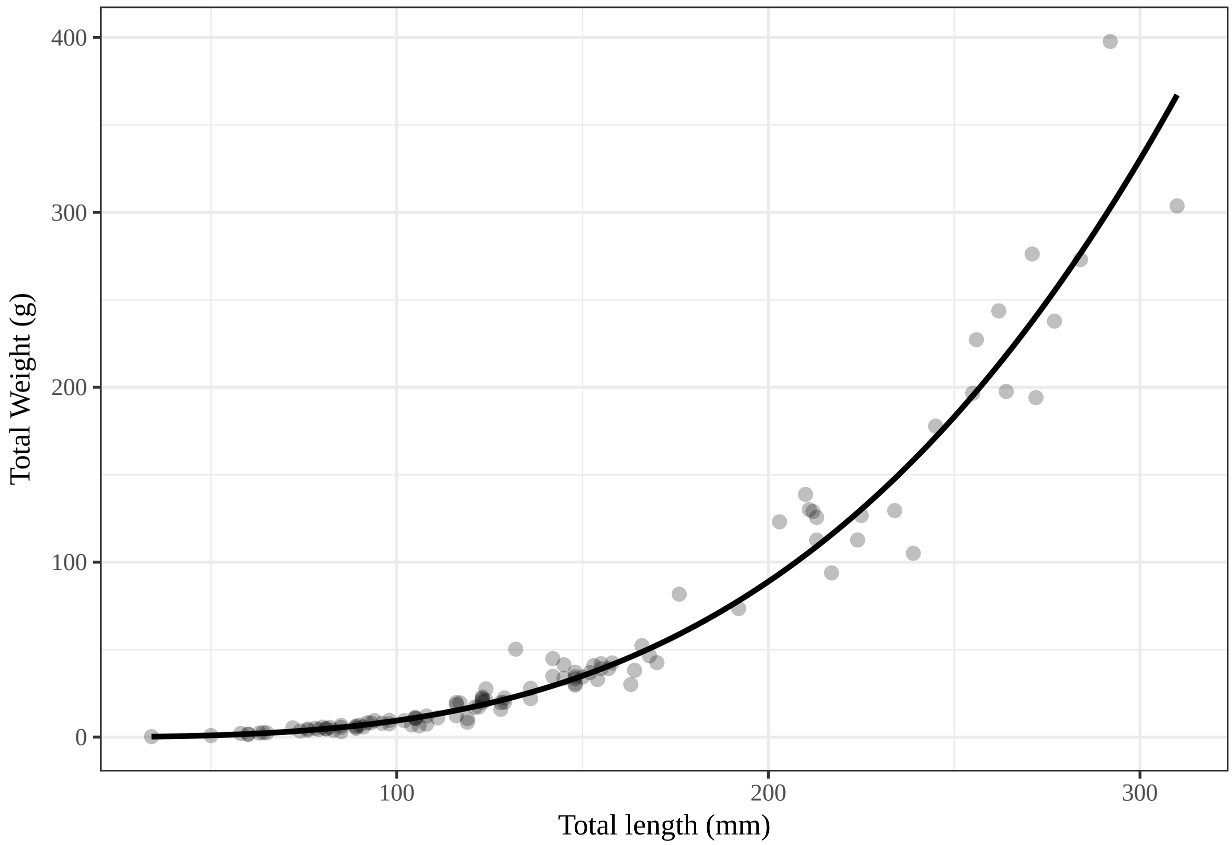


Figure 3: Weight-at-length relationship for 109 lionfish sampled off the coast of Puerto Aventuras, Mexico.

182 ## Review plots

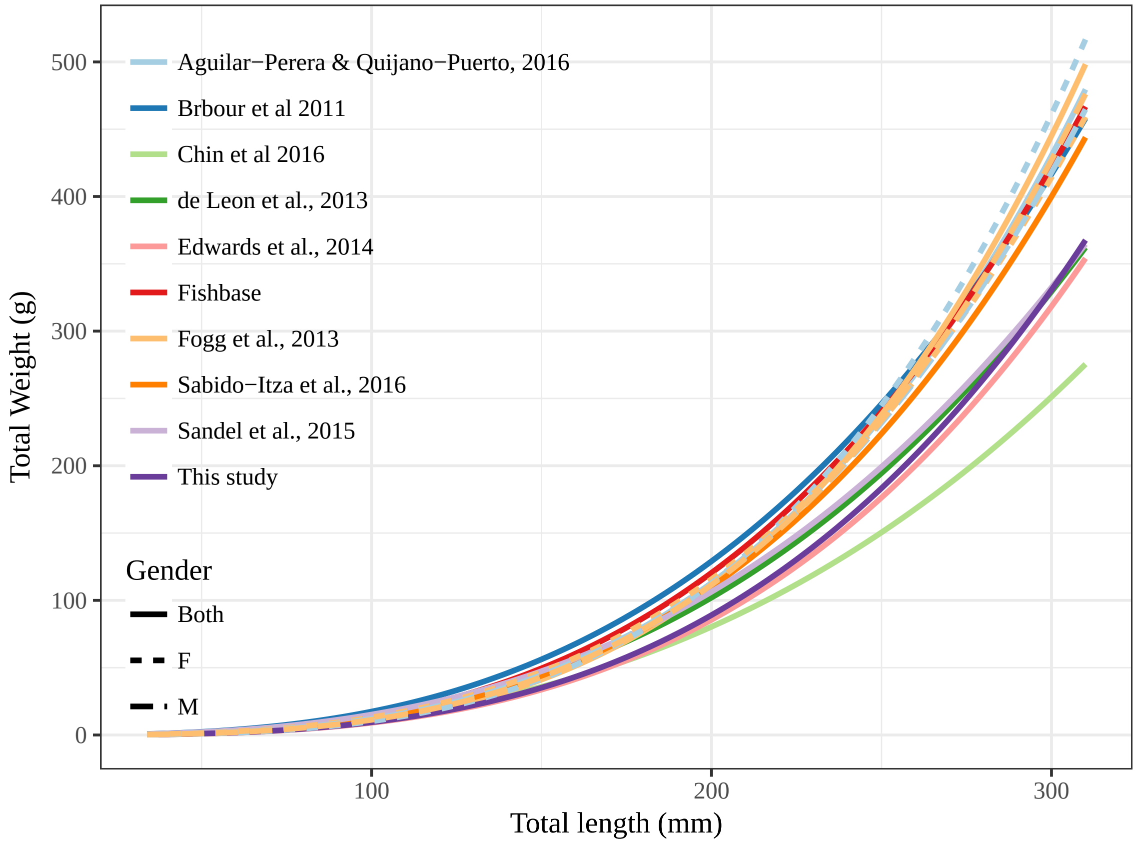


Figure 4: Weight-at-length relationships (n = 14) for eight studies, this study, and FishBase parameters. Colors indicate studies from which the parameters were extracted. Solid lines indicate that the fit was performed for males and females pooled together. Dotted lines indicate that the regression was performed on females, and dashed lines indicate it was performed for males.

183 ## Predictions plot

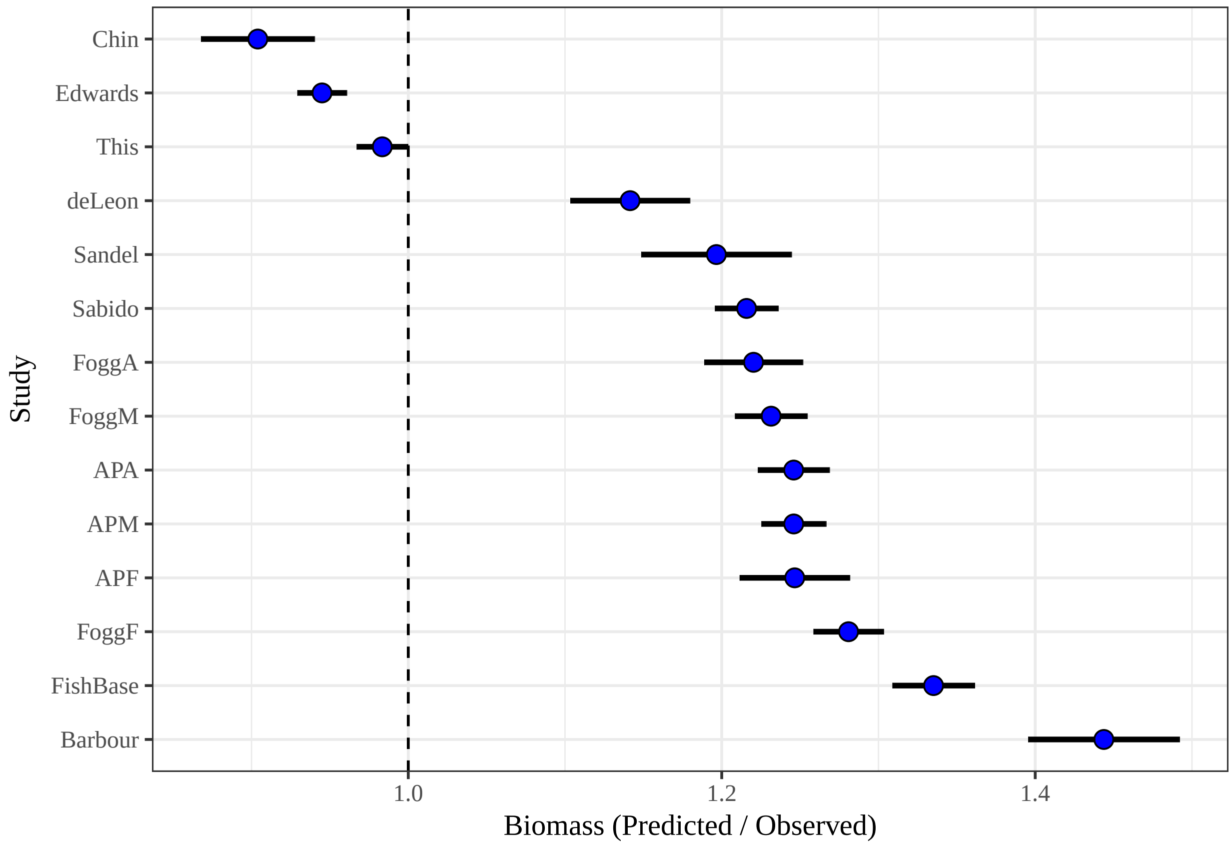


Figure 5: Mean predicted to observed biomass ratios for eight studies, this study, and FishBase parameters. Error bars indicate +/- 1 Standard Error.

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