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# LENGTH-WEIGHT RELATIONS AND CONDITION FACTOR OF *Lutjanus peru* AND *L. guttatus* FROM THE GULF OF CALIFORNIA MEXICO

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**ABSTRACT**. Fulton's condition factor (*k*) and the length-weight relations (LWR) are the most important biological tools in terms of basic aspects of fish population dynamics; they are applicable to strategic plans for the conservation and management of fisheries. A total of 478 snappers *Lutjanus peru* and *L. guttatus* were analyzed from Santa Rosalía, Baja California Sur, in the Gulf of California. The total length (TL) of *Lutjanus peru* ranged from 21 to 55 cm, and total weight oscillated from 215 to 1,920 g, whereas the TL of *L. guttatus* spanned between 21 to 59 cm, with a weight interval from 290 to 1,675 g. The LWR and condition factor were estimated for the two species and intraspecific factors were analyzed (sex, season and maturity stage were analyzed) using Bayesian hierarchical models. The parameters of the LWR equation were similar for the two snapper species ( $\alpha \approx 0.026$ and $\beta \approx 2.8$ ); they both presented negative allometric growth ($p(\beta<3)>85\%$). The *L. peru* growth rate was higher in the warm season ($p(\beta_{warm}>\beta_{cold})\approx 97\%$), while this difference was not as evident in *L. guttatus* ($p(\beta_{warm}<\beta_{cold})\approx 72\%$). The condition factor *k* was greater than 1 for all categories in both species ($p(\mu_k>1)=100\%$), suggesting that they maintain good body condition. This may lead to indicate that year-round marine environmental conditions in Santa Rosalía seem to benefit body conditions, including food availability for both snapper species. This information is useful for future conservation studies and for monitoring snapper catches since the majority of captured *L. peru* individuals were sexually immature.

Keywords: allometric growth, Lutjanidae, Bayesian inference, Santa Rosalía, Snapper.

## Relaciónes peso-longitud y factor de condición de *Lutjanus peru* y *L. guttatus* provenientes del Golfo de California Mexico

**RESUMEN**. El factor de condición de Fulton (k) y las relaciones peso-longitud (LWR) son herramientas biológicas clave para comprender aspectos básicos de la dinámica poblacional de peces, siendo esenciales para establecer planes estratégicos de conservación y manejo pesquero. En este estudio, se analizaron 478 ejemplares de los pargos *Lutjanus peru* y *L. guttatus* provenientes de Santa Rosalía, Baja California Sur, en el Golfo de California. La longitud total (TL) de *L. peru* varió entre 21 y 55 cm, con un peso total de 215 a 1.920 g, mientras que la TL de *L. guttatus* osciló entre 21 y 59 cm, con un peso de 290 a 1.675 g. Se estimaron las LWR y el factor de condición para ambas especies, analizando factores intraespecíficos (sexo, estación y estado de madurez) mediante modelos jerárquicos Bayesianos. Los parámetros de la ecuación LWR fueron similares para ambas especies ($\alpha \approx 0.026$ and $\beta \approx 2.8$) y ambas exhibieron crecimiento alométrico negativo ($p(\beta<3)>85\%$). La tasa de crecimiento de *L. peru* fue mayor en la estación cálida ($p(\beta_{clido}>\beta_{frio})\approx 97\%$), mientras que esta diferencia fue menos evidente en *L. guttatus* ($p(\beta_{warm}>\beta_{cold})\approx 72\%$). El factor de condición k fue superior a 1 en todas las categorías para ambas especies ($p(\mu_k>1)=100\%$), indicando un buen estado corporal. Esto sugiere que las condiciones ambientales marinas en Santa Rosalía a lo largo del año parecen favorecer la condición corporal, incluida la disponibilidad de alimento para ambas especies de pargo. Esta información es valiosa para estudios futuros de conservación y para el monitoreo de las capturas de pargo, considerando que la mayoría de los individuos de *L. peru* capturados eran sexualmente inmaduros.

Palabras clave: Crecimiento alométrico, Lutjanidae, Inferencia Bayesiana, Santa Rosalía, Pargo.

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## INTRODUCTION

Length-weight relationships (LWR) are biologically important estimates applicable to population dynamics, physiology, ecology, and fish conservation (Froese, 2006). Variations in the length and weight of fish have biological implications, as these variations are used to compare growth patterns among species that are taxonomically similar. They are also required parameters to estimate and regulate optimal population catches in fisheries science (Froese *et al.*, 2014; Fayoka *et al.*, 2019; Park *et al.*, 2021). For example, when part of a fish is damaged during sampling or capture, its length can be predicted by converting weight and length data (Froese, 2006; Park *et al.*, 2021).

Fulton´s condition factor (*k*) is widely used in fisheries. This index is based on the relationship between the weight and length of the fish and is used to evaluate welfare during capture (Fulton, 1902; Nash *et al.*, 2006). Both the LWR and the condition factor are fundamental for fisheries science since they serve as indicators of energy reserves, from which the physiological state of fish populations can be inferred (Piddocke *et al.*, 2015; Fayoka *et al.*, 2019; Park *et al.*, 2021). In addition to providing useful informa-

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tion in the form of indirect measures when evaluating reproduction (Lucano-Ramírez *et al.*, 2023), they are usually necessary in the adequate selection of fish in aquaculture (INAPESCA, 2018).

Snappers (family Lutjanidae) are generalist carnivorous predators that inhabit tropical and subtropical waters around the world and are important in fisheries worldwide (Parrish 1987; Allen & Robertson, 1995; Froese & Pauly, 2019; Park *et al.*, 2021). The snappers *Lutjanus peru* (Nichols and Murphy, 1922) and *Lutjanus guttatus* (Steindachner, 1869) are mesopredators that participate in the recirculation and transfer of energy from epifauna to infauna, towards higher trophic levels. The diet of the two species changes mainly from benthic invertebrates in small sizes to a greater consumption of fish in larger sizes (Moreno-Sánchez *et al.*, 2016., Valle-López *et al.*, 2022; Quiroga-Samaniego *et al.*, 2022).

The Pacific red snapper *L. peru* and the spotted rose snapper *L. guttatus* are distributed from the Gulf of California, Mexico, to Peru. In Mexico, they are important in coastal fisheries, with catches throughout the year. There has been an increase in catches in the last 26 years (4,217 and 21,617 tons/year, CONAPESCA, 2020), generating economic benefits close to MXN $533 million. The state of Baja California Sur is one of the three main states that contribute to snapper catches in Mexico (CONAPESCA, 2020).

Despite their commercial and ecological importance, studies on the LWR of these species are scarce in Mexico and are mainly part of reproduction studies based on the body condition of the fish (e.g., Lucano-Ramírez *et al.*, 2023), with no integral comprehensive analysis. Isometric growth has only been reported for *L. peru* in Bahía de la Ventana, Baja California Sur (Barbosa-Ortega 2016), while there are no previous studies on *L. guttatus*. The objective of this study was to obtain information on LWRs and Fulton´s condition factors for the two species and evaluate variations by sex, season, and maturity stage. This is the first study that provides information on the proper management of this fishery in the state of Baja California Sur and the Gulf of California.

## MATERIALS AND METHODS

The specimens used in this study were caught by local artisanal fishers that operate under a commercial fishing license under Mexican laws and regulations. We neither participated in fishing operations nor handled live animals. Specimens of the snappers *L. peru* and *L. guttatus* were captured monthly from August 2016 to October 2017 using a gillnet in the mining port of Santa Rosalía (27°19’45.14” N, 112°15’13.40” W), located in the central-eastern coast of Baja California Sur, Mexico. After capture, the specimens were frozen and transported to the Ichthyological Teaching Laboratory of the Centro Interdisciplinario de Ciencias Marinas of the Instituto Politécnico Nacional (CICIMAR-IPN), where total length (TL, ±0.5 cm precision) and total weight (W, ± 0.01 g precision) were recorded. Sex was determined by direct observation of the gonads. The specimens of *L. peru* that measured more than 40 cm TL were considered adults (Rocha-Olivares, 1991; Barbosa-Ortega, 2016), and the specimens of *L. guttatus* specimens larger than 30 cm TL were considered adults (Lucano-Ramírez *et al.*, 2023).

Two climatic seasons were defined for the year 2016-2017: a warm season that included the months of June, July, August, September, October, and November, and a cold season that included the months of December, January, February, March, April, and May (Valle-López *et al.*, 2021 and Pérez-Rojo *et al.*, 2022).

We analyzed the data with Bayesian hierarchical models. In general, Bayesian inference consists of updating available knowledge about the parameters of statistical models using observed data (Schoot *et al.*, 2021). Hierarchical models are multi-level random-effects models that incorporate uncertainty regarding the parameters at the lowest (group) level in the hierarchy and sequentially transfer it to higher (shared) levels; therefore, they allow the effective investigation of cross-level hypotheses and the minimization of the effect of data imbalance (Gelman *et al.*, 2014).

The models were implemented using the PyMC module (v.5.8.2, Abril-Pla *et al.* 2023) in Python (v.3.11.5, Van Rossum & Drake 2009). Posterior distributions were sampled with four Markov-Monte Carlo chains with a Hamiltonian sampler (NUTS, No-U-Turn Sampler). Chains were run until convergence, i.e., zero divergences during posterior sampling (Betancourt, 2017), with Gelman-Rubin statistics below 1.01 for all parameters (Gelman *et al.*, 2014). The models’ goodness-of-fit were also verified with other graphical diagnostics such as posterior predictive checks, energy plots (Betancourt, 2017; Gabry *et al.*, 2017), and Bayesian “p values” with distributions around 0.5 (Gelman *et al.*, 2014). All posterior distributions had effective sample sizes greater than 2,000. The posterior distributions are summarized in terms of their means and 95% highest density intervals ($HDI_{95\%}$) that represent the areas of highest probability for the true value of the parameter, given the data and the model (Bolstad, 2004; Kruschke, 2015).

### Length-weight relationship

The length-weight relation was obtained with the potential model , where *W* represents total weight, *L* is the total length, and and are parameters that represent the intercept and the growth rate, which indicates growth type, respectively. These parameters were estimated from the linearized model through a base 10 logarithm (Froese *et al.*, 2013): $\log_{10}(TW)=\log_{10}(\alpha TL^{\beta}) \therefore \log_{10}(TW)=\log_{10}(\alpha)+\beta\times\log_{10}(TL)$

Then, the value of α in the potential model is obtained by back-transforming $\log_{10}(\alpha)$ to the original scale. The hierarchical Bayesian model was specified as follows:

Species-level (shared) prior distributions (i):

$\theta_{(p,i)}$~MvNormal($\mu$=[$log_{10}(\alpha)$=-1.5,$\beta$=3],Σ=Σ)

Normal bivariate distribution for the coefficients (p)...$\log_{10}$ (α) and $\beta$ for each species. This prior distribution captures the negative correlation between the intercept and the slope, given by the covariance matrix Σ. The means are the general prior distributions proposed by Froese *et al.* (2013):

$\log_{10}(\alpha)$=-1.5, $\beta$=3

Σ~LKJ(n=2,η=1,σ=Half Cauchy(β=[0.3,1])):

Lewandowski-Kurowicka-Joe prior distribution (LKJ, Lewandoski *et al.*, 2009), with standard deviation for $\log_{10}$ (α)=0.3 and β=1 (Froese *et al.*, 2013).

$\epsilon_j$~Exponential(λ=2): Regularizing prior distribution for the model error.

$\nu_i$~Exponential(λ=1/30)+1: Shifted exponential distribution moving between a model with normal error (μ≥30) and a model with longer tails (μ<30).

Group-level (j) prior distributions:

$\log_{10}(\alpha)_{i,j}$Normal($\mu=\theta_{\log_{10}(\alpha),i}$,σ=0.3): Normal distribution centered on the $\log_{10}(\alpha)$ parameter for the species.

$\beta_{i,j}$~Normal($\mu=\theta_{\beta,i}$,σ=1): Normal distribution centered on the β parameter for the species.

Log-log Linear Model:

$\mu_{\log_{10}(TW)_{i,j}}=\log_{10}(\alpha)_{i,j}+\beta_{i,j} * \log(TL)$

Likelihood:

$\log_{10}(TW)$~Student t ($\mu=\mu_{\log_{10}(TW)_{i,j}}$),$\sigma=\epsilon_{i,\nu}=\nu_i$ )

Student's t likelihood that allows making a robust inference of the parameters (Kruschke, 2013).

Interspecific (i.e., *L. peru* vs. *L. guttatus*) and intraspecific (i.e., cold versus. warm season, females versus males, and immature versus mature) comparisons of the intercept and the growth rate parameter β m were carried out by subtracting the posterior distributions of the parameters between each pair of groups and obtaining the probability that this difference was greater than or less than 0 (null difference). The values relative to α are presented with three decimal positions due to their intrinsic small variation in similar species (Froese *et al.* 2013).

**Condition factor**

The condition factor *k* was calculated for each individual as $k = 100\frac{W}{L^3}$, where values greater than 1 suggest good body condition (Froese 2006). The mean of the calculated condition factors estimates was estimated for each species and group within them, following a specification similar to the length-weight relationship model:

Prior distributions at the species (i) level:

$\mu_i$~Normal (μ=1,σ=2)

$\sigma_i$~Exponential(λ=2)

Prior distributions at the group (j) level:

$\mu_{i,j}$~Normal($\mu=\mu_i,\sigma=\sigma_i$ )

$\sigma_{i,j}$~Exponential (λ=2)

Likelihood:

k~Student t($\mu=\mu_{i,j},\sigma=\sigma_{i,j},\nu=\nu_i$)

The posterior distributions of mean *k* for each species and group were compared for each factor in the same manner as the LWR parameters.

## RESULTS

A total of 478 snappers were captured, 296 of which were Pacific red snappers *Lutjanus peru* and 158 red rose snappers *L. guttatus*. A total of 123 males and 173 females of *L. peru* were recorded; 242 were immature and 54 were mature. A total of 150 specimens were caught in the warm season and 146 in the cold season. The specimens of *L. peru* ranged in size from 21 to 55 cm TL and 215 to 1,920 g. A total of 112 females and 46 males of *L. guttatus* were captured; 2 were immature and 156 were mature. A total of 58 specimens were caught in the warm season and 100 in the cold season. *L. guttatus* specimens ranged from 21 to 59 cm TL and 290 to 1,675 g.

**Length-weight relationship of *L. peru* and *L. guttatus***

The distributions of the parameters of the length-weight relations (LWRs) are shown in Table 1 and the models adjusted to each species are shown in Figure 1. The coefficients of determination ($R^2$) for the linear (log-log) model were 0.87±0.03 at the species level; 0.89±0.02 for the seasons, 0.87±0.03 for the sexes, and 0.87±0.03 for maturity stages. The LWRs of *L. peru* and *L. guttatus* were similar (α≈0.026 and β≈2.8; Fig. 2) with the growth of the two species and categories with negative allometric (p(β<3)>85%, Table 1). There were intraspecific differences only between seasons (Fig. 2). The warm season had a higher intercept than the cold season for both species ($p(\alpha_{cold}<\alpha_{warm})>79\%$). The growth rate of *L. peru* was greater in the warm season ($p(\beta_{warm}>\beta_{cold})\approx97\%$), whereas differences were less probable in *L. guttatus* ($p(\beta_{warm}<\beta_{cold})\approx72\%$). The posterior distributions of Fulton's condition factor (*k*) ranged from 1.19 to 1.51 in the two species (Fig. 3). All categories analyzed for the two species had means greater than 1 , which suggests that they were in good body condition regardless of season, sex, or stage of maturity.

Table 1. Distribution of the length-weight relationship parameters in the snappers *Lutjanus peru* and *Lutjanus guttatus* for each analyzed group. α: intercept, β: growth parameter. Shown as mean and 95% highest density intervals μ;[$HDI_{2.5\%}$,$HDI_{97.5\%}$]

| Group | n | α | β | p(β<3) |
|---|---|---|---|---|
| *L. peru* | 296 | 0.025; [0.020, 0.030] | 2.81; [2.75, 2.86] | 100 % |
| Season | | | | |
| Cold | 146 | 0.021; [0.017, 0.027] | 2.85; [2.78, 2.91] | 100 % |
| Warm | 150 | 0.033; [0.024, 0.044] | 2.74; [2.65, 2.82] | 100 % |
| Sex | | | | |
| Female | 173 | 0.024; [0.019, 0.030] | 2.82; [2.75, 2.89] | 100 % |
| Male | 123 | 0.027; [0.02, 0.036] | 2.78; [2.70, 2.87] | 100 % |
| Maturity | | | | |
| Immature | 242 | 0.020; [0.013, 0.027] | 2.88; [2.77, 2.97] | 99 % |
| Mature | 54 | 0.018; [0.007, 0.032] | 2.91; [2.72, 3.12] | 81.2 % |
| *L. guttatus* | 158 | 0.027; [0.013, 0.042] | 2.79; [2.63, 2.94] | 99.7 % |
| Season | | | | |
| Cold | 100 | 0.043; [0.014, 0.077] | 2.70; [2.48, 2.90] | 99.4 % |
| Warm | 58 | 0.028; [0.013, 0.045] | 2.78; [2.61, 2.94] | 99.7 % |
| Sex | | | | |
| Female | 112 | 0.026; [0.012, 0.042] | 2.81; [2.64, 2.97] | 99.1 % |
| Male | 46 | 0.035; [0.008, 0.073] | 2.75; [2.48, 3.06] | 95 % |
| Maturity | | | | |
| Immature | 2 | 0.037; [0.001, 0.113] | 2.88; [2.30, 3.45] | 65.1 % |
| Mature | 156 | 0.023; [0.012, 0.035] | 2.83; [2.68, 2.99] | 98.7 % |

## DISCUSSION

This is the first study to report on the length-weight relations (LWR) as well as body condition factor (*k*) of the Pacific red snapper and red rose snapper in Santa Rosalía, Baja California Sur, Mexico. Growth rate estimates in this study were within the ranges reported for other fish species in the family Lutjanidae worldwide (Froese, 2006; Piddocke *et al.*, 2015; Fayoka *et al.*, 2019; Park *et al.*, 2021).

The growth type presented by the two snappers was negative allometric (β<3) and was consistent for the categories analyzed (sexes, seasons, and maturity stages). This indicates that growth was greater in length than weight (Ricker, 1975; Froese, 2006), resulting in an elongated body shape. Allometry has also been reported for most snappers (Park *et al.*, 2021), green snappers (Fayoka *et al.*, 2019), and groupers (Irigoyen-Arredondo *et al.*, 2016), which could be reflecting their behavior mobile, which is to say, it depends on speed, the search and hunting of prey, the availability of food (variations in diet), and environmental conditions (upwellings, primary productivity) (Fayoka *et al.*, 2019; Park *et al.*, 2021). Friedman *et al.* (2020) suggested that the elongated body shape of marine pelagic fish is an evolutionary adaptation that gives them the advantage of constant locomotion in open waters and the ability to easily interact with the benthos, water column, and surface to feed and find shelter, or flee from predators, compared to other body forms.

There is no detailed information on the LWR of *L. guttatus*. In contrast to this study, isometric growth (β≈3) was reported for *L. peru* south of Santa Rosalía (La Ventana, Baja California Sur, Barbosa-Ortega, 2016). Based on these differences, we hypothesize that snappers distributed in tropical environments present allometric growth, as has been reported for the southeastern Atlantic Ocean (Fayoka *et al.*, 2019). In contrast, isometric growth of fish in the family Lutjanidae has been reported in regions of the Middle East, possibly reflecting environmental conditions, food availability, and regulation of fishing during reproduction (Fayoka *et al.*, 2019; Park *et al.*, 2021; Nair *et al.*, 2021). We believe that the variances between those studies and ours are due to differences in the behavior and type of feeding strategy of the fish studied. Snappers distributed in the Gulf of California and the Mexican Pacific tend to be very mobile in the water column. Furthermore, a large part of their feeding strategy consists in searching for and capturing prey (Quiroga-Samaniego *et al.*, 2022), leading to an accelerated metabolism and the creation of an elongated body. However, these differences could also be attributed to extrinsic and intrinsic factors (e.g., maturity stage, feeding, reproductive stage, season, etc.), the gear used to capture the fish, the preservation techniques used, and the geographic area (Nair *et al.*,

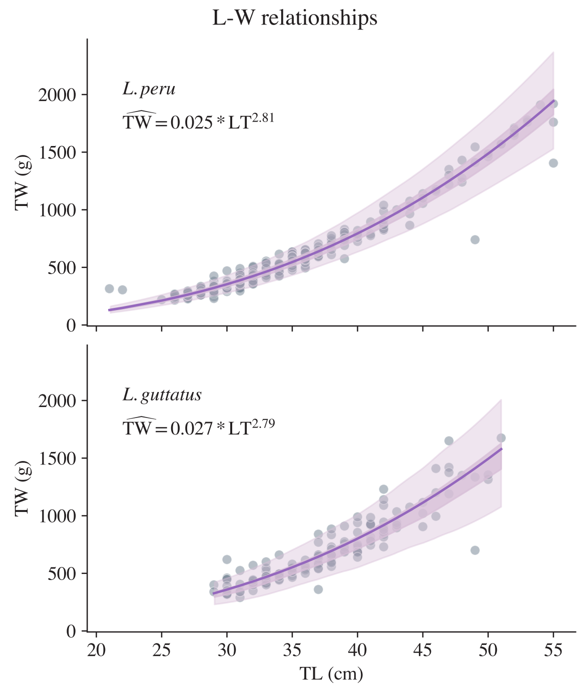


Figure 1. Length-weight relationship distributions for *L. peru* and *L. guttatus*. The solid line represents the distribution mean, and the shaded areas show the 50% (light color) and 95% (darker color) highest density intervals.

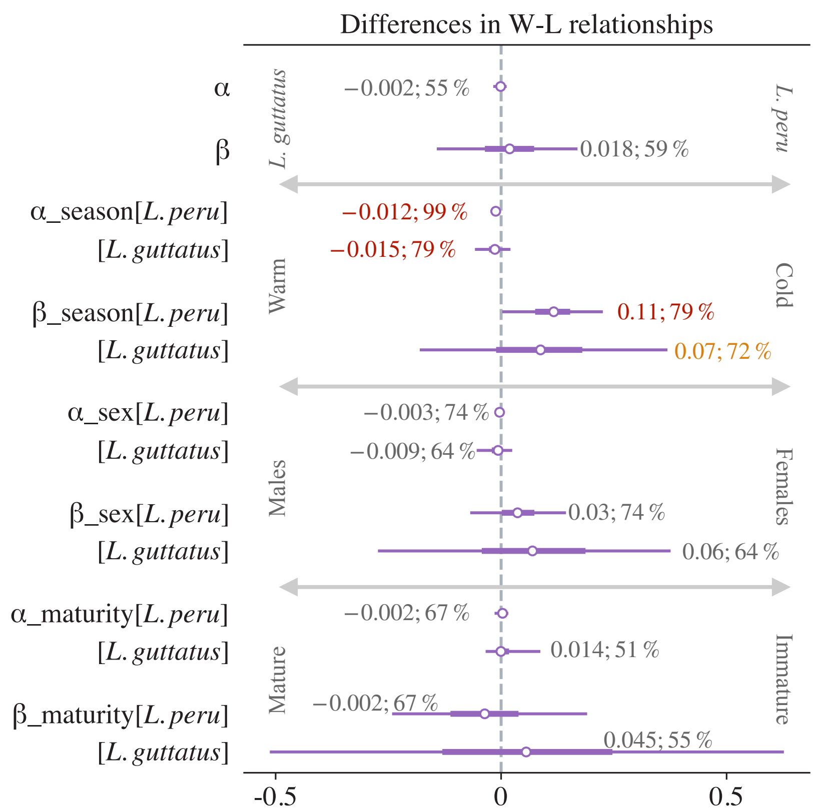


Figure 2: Differences in posterior distributions of the length-weight relationship parameters for each species and group. The dots show the mean, the thick lines show the 50% highest density intervals, and the thin lines show the 95% highest density intervals. The vertical dashed line shows the reference for a null difference (0) in the parameter.

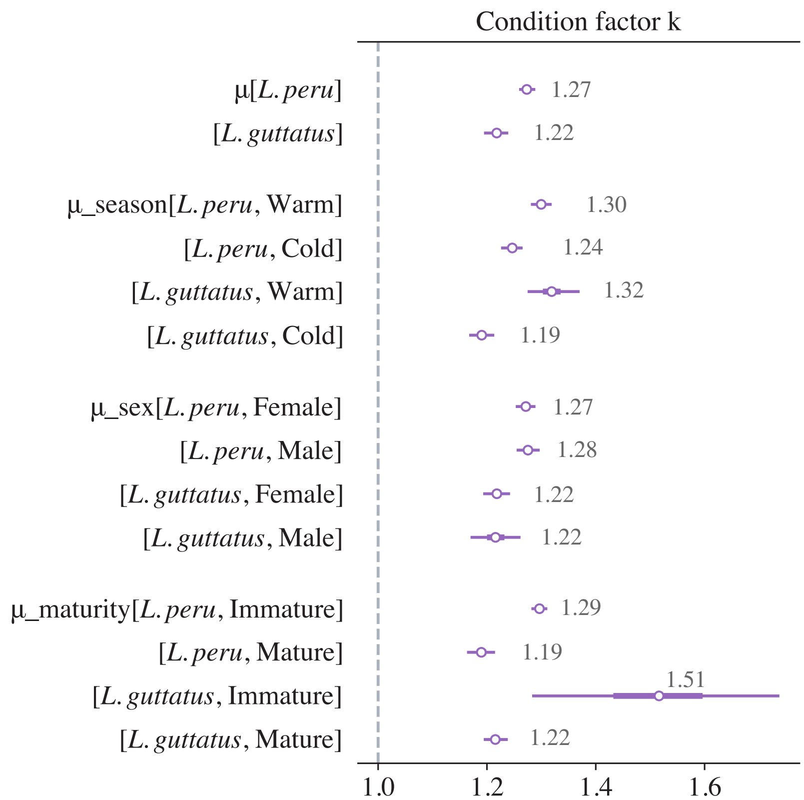


Figure 3: Posterior distributions of the condition factor (k) mean. p($\mu_k$>1)=100% in all cases. The vertical dashed line shows the reference value (1) above which an individual is considered to have a good body condition (Froese 2006).

2021; Park *et al.*, 2021).

Environmental conditions, feeding, and reproduction are the main factors that affect the well-being of fishes (Nash *et al.*, 2006). Consequently, the fact that the two snapper species were in good body condition (k>1) in Santa Rosalia, regardless of the categories analyzed, suggests that oceanographic conditions within the Gulf of California promote food availability throughout the year (Valle-López *et al.*, 2021; Pérez-Rojo *et al.*, 2022; Quiroga-Samaniego *et al.*, 2022), or that at least there are no limiting conditions (Nash *et al.*, 2006). This contrasts with other regions such as the Gulf of Oman, the Arabian Gulf, and the southeastern Atlantic Ocean, where congeneric fishes have shown great variability in body condition decline depending on season, food availability, and primary productivity, respectively (Park *et al.*, 2021).

Finally, we believe that our findings can be used in the assessment of snapper populations, as well as in the creation of strategic fishing plans. This is particularly important for the Pacific red snapper *Lutjanus peru*, as commercial catches are affecting sexually immature fishes that have not yet reproduced (*n*=242, 21-39 cm total length). On the other hand, catches of the red rose snapper *L. guttatus* were mostly directed at mature fishes (only two immature specimens were caught).

In this regard, using hierarchical Bayesian models allowed us to assess the LWR and k for every group, even with as few as two samples. Hierarchical Bayesian models partially pool the data and "shrink" the group-level estimates towards the shared parameters (Gelman *et al.* 2014), meaning that every sample, regardless of the group, informs every group-level posterior. Still, the uncertainty revolving around those groups is considerable, reflected by broader highest-density intervals (Table 1, Fig. 3), and thus, their parameters should not be taken as a conclusion but rather as the best estimate given the limited data. Still, this was only possible due to the specification of the species-level priors based on Froese *et al.* 2013, since using inadequate (vague/diffuse) priors may lead to more biased estimates than frequentist methods (McNeish 2016).

## CONCLUSION

Our results provide new and relevant information on the Pacific red snapper and red rose snapper that inhabit Santa Rosalia, Baja California Sur, in the Gulf of California. These results contribute to future studies on snapper conservation and could be useful for the adequate monitoring of catches, since they are species of great commercial interest in the state of Baja California Sur.

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