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Length-weight relationships for abundant coral reef fish species from eight islands in French Polynesia

by

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Résumé. – Relations taille-poids pour les espèces de poissons abondantes des récifs coralliens de huit îles de Polynésie française.

Nous présentons ici les relations longueur-poids (LWR) pour 11 espèces de poissons de récif corallien de huit îles de Polynésie française. Au total, 1930 poissons ont été collectés dans cinq îles de l'archipel de la Société (Moorea, Tahiti, Raiatea, Huahine, Tetiaroa) et dans trois atolls de l'archipel des Tuamotu (Takapoto, Tikehau et Rangiroa). Ces poissons couvrent plusieurs niveaux trophiques, avec des planctonophages, des herbivores et des carnivores, et sont parmi les espèces les plus abondantes de la région. Les estimations comprennent des LWR pour des espèces qui n'ont jamais été publiées auparavant ou qui ne sont pas disponibles dans la littérature ou les bases de données accessibles. Les mesures de longueur totale (TL : précision de 0,1 cm) et de poids total (P : précision de 0,01 g) ont été effectuées. Ces estimations augmentent le nombre de LWR disponibles et robustes pour les poissons des récifs coralliens, ce qui permet de mieux comprendre la croissance de ces espèces. Avec un focus plus particulier sur les espèces de petite taille, parmi les plus abondantes observées lors des comptages visuels sous-marins, ces estimations permettront aux gestionnaires des ressources marines et aux scientifiques locaux de caractériser les biomasses de poissons en Polynésie française avec une plus grande précision.

Key words. – Coral reef fishes – French Polynesia – Length-weight relationships – Morphology – Aquarium species – Biomass.

Coral reef fish assemblages and their associated fisheries experience distinct challenges for management. In particular, the combination of high species diversity among coral reef fishes and limited availability of critical life history information makes accurate assessments of reef fish assemblage structure difficult. Resource managers and scientists frequently conduct underwater visual census surveys to assess the structure of fish assemblages, with the goal of tracking patterns of ecological change and providing insight into the fisheries potential of an area (Caldwell *et al.*, 2016). A common goal is to calculate biomass based on the known relationship between fish length and weight, which allows estimation of overall biomass, as well as biomass in specific categories of interest (fisheries targets, trophic category), given the importance of size to fisheries value and ecological function (*e.g.*, predation, fecundity). Size-based assessments are conducted to examine patterns of exploitation and to estimate the health of populations of interest. However, length-weight relationships (LWR) are known only for a restricted set of species, and robust data are available for even fewer (Kulbicki *et al.*, 2005; Froese, 2006). Further, patterns of growth for reef fishes are different across biogeographic regions and in many cases, LWR are likely unique to each region. In this study, we report length-weight relationships for 11 reef fish species from eight islands in French Polynesia: *Acanthurus nigricans* (Linnaeus, 1758) (Acanthuridae); *Ctenochaetus striatus* (Quoy & Gaimard, 1825) (Acanthuridae); *Paracirrhites arcatus* (Cuvier, 1829) (Cirrhitidae); *Pycnochromis iomelas* (Jordan & Seale, 1906) (Pomacentridae); *Pycnochromis margaritifer* (Fowler, 1946) (Pomacentridae); *Pycnochromis vanderbilti* Fowler, 1941 (Pomacentridae); *Plectroglyphidodon aureus* (Fowler, 1927) (Pomacentridae); *Plectroglyphidodon fasciolatus* (Ogilby, 1889) (Pomacentridae); *Cephalopholis urodeta* (Forster, 1801) (Serranidae); *Pseudanthias pascalus* (Jordan & Tanaka, 1927) (Serranidae) and *Pseudanthias mooreanus* (Herre, 1935) (Serranidae). While only a few of these species are of interest as food fish, they are some of the most abundant members of the community – in one case, a single species (*Ctenochaetus striatus*) accounts for 37% of the total fish density at a given site (Madi Moussa, 2009). In addition, all species studied here are of commercial interest to the aquarium industry as ornamental fishes, whose populations are often understudied and life histories poorly understood (Wabnitz *et al.,* 2003). Many of the species can be found commonly available online on a number of aquarium websites (B. French, pers. obs., 2022). Five of the eleven species studied are damselfishes (Pomacentridae), which are reported to make up nearly half of the aquarium trade, based on analysis of 102, 928 trade records from the years 1988 to 2003, as integrated into the Global Marine Aquarium Database (Wabnitz *et al.*, 2003). These estimates should therefore be of substantial value for local science and management, not only as they reflect the region-specific LWR to enable more accurate assessments of coral reef fish assemblages, but because they provide information for an industry with critical knowledge gaps.

MATERIALS AND METHODS

Fishes were collected from five islands in the Society Islands archipelago of French Polynesia in November 2018, February-

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March 2019, and May-June 2021, and from three islands in the Tuamotu archipelago in September-October 2021. All fishes were collected from 5-15 m depth using three-prong spears or fish anaesthetic with hand nets (1-mm mesh) and barrier nets (6-mm mesh). For all collections, AQUI-S® (10% eugenol) or clove oil was used as an in-water anesthetic, and fish were subsequently humanely euthanized after collection using protocols in UC San Diego IACUC protocol #S9392, which provided ethical approval for this study. Fishes were collected from the forereef of the respective islands between 8-18 m depths. Morphometric data, including standard length, fork length, total length (all length measurements: 0.1 cm precision) and weight (W: 0.01 g precision) were collected shortly after collection wherever possible. When field conditions prevented immediate collection of accurate length and weight data due to the difficulty of obtaining such measurements on small boats, fishes were photographed immediately in the field with rulers and frozen for later analysis in the laboratory. In the laboratory, frozen and thawed weights were obtained for all fishes collected from the Society Islands in 2019, regardless of whether in-field weight data was obtained. For fishes collected from the Society Islands and Tuamotus in 2021, weights were only taken in the laboratory. Measurements of standard length, fork length, total length, and body depth were taken using ImageJ (Schneider *et al*., 2012) for all fishes collected from the Society Islands in 2019 and 2021 and from the Tuamotus in 2021. Calipers were used to collect measurements of standard length, fork length, total length, and body depth for all fishes collected from Moorea in 2018. To account for the potential effects of freezing on fish body weight, we used conversion factors to convert frozen weights to presumed 'field weights' using established conversion factors (Akiona *et al*., 2022) to account for the loss of mass that occurs during the freezing process. Smaller fishes lose a higher proportion of weight during the freezing process due to greater surface-to-volume ratios. However, no appreciable differences in parameter estimates for the conversion function were observed from species spanning different ranges of body sizes, and we therefore calculated 'field' or 'fresh' weights using the following equation:

$$W_{\text{Fresh}} = W_{\text{Frozen}} + (0.0946)W_{\text{Frozen}}^{(0.5620)}$$

All subsequent analysis used the mean weight from three values (frozen weight, thawed weight, converted field weight) to determine LWR.

To calculate LWR, we fit a standard length-weight model to all species using:

$$W = aL^b$$

where W is the weight of the fish, L is the length of the fish, parameter a is the scaling coefficient for the weight at length of the fish species (slope), and parameter b is the shape parameter for the body form of the fish species (intercept). In all cases we used total length in cm for our measure of L. Parameters a and b were calculated using the linear regression of the log-transformed equation to account for heteroscedasticity in the untransformed relationship:

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

where $\log(a)$ is the intercept and b is the slope. Statistical analysis was conducted in the statistical language R Version 3.6.1 (R Core Team, 2022). As measurement errors can cause outliers that bias the estimates of length-weight parameters, we removed any outliers that were likely to be the result of errors in measurement. Outliers were defined as any datum that was four or more standard deviations away from the mean model fit in log-log space, as in Kamikawa *et al*. (2015). We then re-fit the regression equations after omitting the outliers. Species were included only if the coefficient of determination (r^2) of the model fit was 0.6 or greater. For example, LWR were also collected for *Pycnochromis xanthura* (n = 7) and *Pycnochromis acares* (n = 26), but are not reported, on the basis of poor model fits ($r^2 = 0.538$ and $r^2 = 0.237$, respectively). All parameter estimates were compared to the Bayesian prediction of parameters for each species using FishBase (Froese and Pauly, 2022).

RESULTS

A total of 1,930 individual fish were collected and analyzed for length-weight relationships (Table I). Of these, 1,889 individual fishes were retained for calculation of relationships after the removal of outliers. We report increases in reported maximum lengths for two species (*Pseudanthias mooreanus* and *Pycnochromis vanderbilti*) when compared with values available in the published literature and FishBase (Froese and Pauly, 2022). Nine of the estimated parameters fall outside the range of previous predictions on accessible databases based on Bayesian predictions generated for each species based on body shapes (Froese *et al*., 2014), with *a* values higher than the 95% confidence interval of Bayesian prediction and *b* values lower than the 95% confidence interval of Bayesian prediction.

Table I. – Length-weight relationships ($W = aL^b$) for 11 fish species from French Polynesia (Society and Tuamotu Archipelagos). Abbreviations: a, intercept; b, slope; CI, confidence interval; L_{max}, maximum total length; L_{min}, minimum total length; n, number of individuals; r^2, coefficient of determination; W_{max}, maximum total weight; W_{min}, minimum total weight. † Expanded size range. * Higher than 95% CI of Bayesian prediction. ** Lower than 95% CI of Bayesian prediction. Gray shading: either no reported a-b values in the literature, or reported a-b values based on estimates from one individual.

Family	Scientific name	n	L_{min} (cm)	L_{max} (cm)	W_{min} (g)	W_{max} (g)	a	95% CI of a	b	95% CI of b	r^2
Acanthuridae	*Acanthurus nigricans*	218	5.9	20.4	10.36	207.43	0.02400	0.0565-0.0822	2.988	2.8952-3.0809	0.949
Acanthuridae	*Ctenochaetus striatus*	224	8.8	22.3	14.76	199.14	0.08471*	0.0509-0.1411	2.424**	2.2491-2.5995	0.778
Cirhhitidae	*Paracirrhites arcatus*	215	3.4	11.8	0.59	44.5	0.01810	0.0140-0.0233	3.002	2.8867-3.1180	0.927
Pomacentridae	*Pycnochromis iomelas*	266	2.1	6.7	0.18	4.23	0.04583*	0.0370-0.0568	2.409**	2.2757-2.5429	0.829
Pomacentridae	*Pycnochromis margaritifer*	203	2.8	8.2	0.34	8.06	0.03503*	0.0271-0.0452	2.607**	2.4619-2.7518	0.883
Pomacentridae	†*Pycnochromis vanderbilti*	17	3.0	6.5	0.50	2.80	0.03424*	0.0201-0.0582	2.446**	2.0846-2.8079	0.923
Pomacentridae	*Plectroglyphidodon aureus*	37	6.3	11.3	4.75	29.44	0.03243*	0.0095-0.1103	2.854**	2.3122-3.3396	0.794
Pomacentridae	*Plectroglyphidodon fasciolatus*	238	5.9	10.4	7.43	28.90	0.08345*	0.0451-0.1546	2.428**	2.1425-2.7136	0.600
Serranidae	*Cephalopholis urodeta*	217	11.0	21.0	18.24	148.46	0.03894*	0.0242-0.0625	2.707**	2.5371-2.8759	0.823
Serranidae	*Pseudanthias pascalus*	187	2.1	18.2	0.08	28.28	0.02925*	0.0231-0.0371	2.530**	2.3950-2.6651	0.907
Serranidae	†*Pseudanthias mooreanus*	67	3.5	10.6	1.61	8.30	0.12891*	0.1183-0.2318	1.813**	1.6346-1.9921	0.871

DISCUSSION

Parameter estimates for length-weight relationships in fishes are known to vary by region and with environmental conditions, making region-specific parameters especially important, although challenging to collect for high-diversity fisheries with little available data. The aim of our study was therefore two-fold: 1) to increase the set of robust data on these fishes by providing parameter estimates for species that do not have published LWR in the literature or databases and for those with parameter estimates based on small sample sizes, and 2) to provide the area-specific LWR for French Polynesia for the target reef fish species. Our estimates include length-weight parameters for multiple species that are not represented in the literature or databases (*Pycnochromis vanderbilti*, *Pseudanthias mooreanus*), for those with reported relationships that are based on low sample sizes (*Pseudanthias pascalus, Pycnochromis iomelas*), and for those with parameters that are under doubt due to low sample size (*Plectroglyphidodon fasciolatus*) in databases (FishBase, Froese and Pauly, 2022). Many of our estimated parameters fall outside the range of the Bayesian predictions for each species based on body shapes (Froese *et al*., 2014).

In order to track patterns of change in fish assemblages, long-term monitoring is essential. Our parameter estimates therefore cover some of the most abundant species observed in the underwater visual surveys at long-term monitoring sites of coral reefs in French Polynesia (Galzin and Legendre, 1987; Galzin *et al*., 2016). In addition, all of the species studied here are of commercial interest as either food fish or ornamental fishes in the marine aquarium trade (Lecchini *et al*., 2006). It has been estimated that between 90-99% of exploited marine ornamental fishes are directly collected from the environment (Sadovy and Vincent 2002; Wabnitz *et al*., 2003), in part due to difficulties of maintenance and captive breeding in aquaria. As such, more accurate information on the growth and condition of these fishes in their natural environments is essential. The provision of these LWR therefore allows for improved accuracy of biomass calculations and growth of coral reef fishes from the region, with a particular focus on some of the most abundant, small-bodied species encountered in underwater visual surveys in the region.

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Electronic Supplementary Material

Supplementary Figures S1-S11: Plot of total length (cm) by weight (g) for all eleven reef fish species on a log-log scale.

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