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Vahine Rurua, Philippe Béarez, Aymeric Hermann, Eric Conte. Length and weight reconstruction of *Chlorurus microrhinos* (Scaridae) from isolated cranial bones and vertebrae. *Cybium: Revue Internationale d'Ichtyologie*, 2020, 44 (1), pp.61-68. 10.26028/cybium/2020-441-008 . hal-03021586

HAL Id: hal-03021586

<https://hal.science/hal-03021586>

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Length and weight reconstruction of *Chlorurus microrhinos* (Scaridae) from isolated cranial bones and vertebrae

by

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Submitted: 10 Apr. 2019
Accepted: 28 Feb. 2020
Editor: O. Otero

Key words

Osteometry
Scaridae
Length-weight
relationship
Length estimation
Pacific Ocean

Abstract. – Parrotfishes are commonly exploited in artisanal fisheries in tropical and subtropical areas. Given their prolonged use, they are common finds in archaeological sites from Oceania. Despite their high occurrence in archaeozoological assemblages, the degree to which they have been exploited is difficult to estimate without any length and weight data. Here, we present an osteometric model for *Chlorurus microrhinos*, an ubiquitous species from the west-central Pacific Ocean, based on reliable body-length reconstruction from isolated skeletal parts. We collected 30 specimens from French Polynesia ranging between 336–713 mm total length and 304–5341 g fresh weight. The length-weight relationship was $W = 3.36E-06 * FL^{3.2960}$ with r^2 higher than 0.9. The model is based on neurocranium, premaxilla, dentary, maxilla, anguloarticular, quadrate, hyomandibula and the upper and lower pharyngeals. For each bone, three measurements were taken and the values were plotted against the fork length. All selected bones have at least one regression equation with a high r^2 (> 0.9) allowing reliable estimation of length and weight of *C. microrhinos* from its skeletal components. This study provides useful data for studies where bone conservation is affected by variable taphonomic factors or differential preservation, such as the stomach content of scarid predators, or archaeological and paleontological assemblages in Oceania.

Résumé. – Reconstitution de la taille et du poids chez *Chlorurus microrhinos* (Scaridae) à partir d'éléments squelettiques isolés.

Les poissons-perroquets sont des espèces régulièrement exploitées par les pêcheries artisanales des régions tropicales et subtropicales. Leur forte consommation est attestée parmi les sites archéologiques d'Océanie, et ce depuis les premières installations des communautés humaines dans les archipels. Malgré cette forte occurrence parmi les assemblages archéozoologiques, l'estimation de leur exploitation est difficile à évaluer par manque de connaissances sur la taille et le poids des captures des spécimens archéologiques. Nous proposons ici un modèle ostéométrique pour *Chlorurus microrhinos*, une espèce bien représentée dans l'océan Pacifique. Sur la base d'une trentaine d'individus collectés (longueur totale de 336 à 713 mm et poids de 304 à 5341 g), la relation poids-longueur obtenue est $W = 3,36E-06 * FL^{3,2960}$ ($r^2 > 0,9$). Le modèle ostéométrique de la présente étude se base sur les éléments crâniens (neurocrâne, prémaxillaire, dentaire, maxillaire, articulaire, carré, hyomandibulaire, pharyngiens inférieurs et supérieurs) ainsi que sur les vertèbres. Toutes les mesures d'éléments isolés du squelette sont corrélées à la taille et au poids des individus de *C. microrhinos* par des équations de régression robustes ($r^2 > 0,9$) permettant des estimations fiables. Ces modèles pourront être appliqués à des contextes archéologiques ou paléontologiques aussi bien qu'à des études analysant les contenus stomacaux des prédateurs de l'espèce.

Parrotfishes (Scaridae) constitute a group of marine species widely represented in tropical and subtropical shallow waters, especially in coral reef ecosystems. An abundance of 100 species are currently recognized (Parenti and Randall, 2011), most of which occur in the Indo-Pacific Ocean, and 22 in French Polynesia (Siu *et al.*, 2017). They are common in a wide range of habitats (coral reefs, rocky coastlines and seagrass beds) and form large schools of often mixed-species that are active in the lagoon during the day (Myers, 1999). Due to the bio-erosive effect of their activity, parrotfishes play a key-role in marine ecosystems (Bellwood and Choat, 1990). Moreover, they also play a major role in human diet, as shown by the importance of their catch in small-scale

fisheries (Rodriguez Santana and Arnay de la Rosa, 1999). *Chlorurus microrhinos* (Bleeker, 1854), a large and ubiquitous species from the west-central Pacific Ocean, is heavily exploited as a primary food because of its culinary and cultural values in local communities (Choat *et al.*, 2012).

Parrotfishes have played an important role in the subsistence of Pacific island societies since the first settlement on these islands. However, based on the archaeozoological record from Western Micronesia to Polynesia, it appears that parrotfishes occur in greater abundance (in terms of NISP: Number of Identified Specimens) in reef island assemblages than in islands without coral reefs as is the case in the Marquesas archipelago (e.g. Leach *et al.*, 1997; Rolett, 1998;

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Davidson *et al.*, 1999; Ono and Clark, 2012; Weisler and Green, 2013; Allen, 2017; Cannon *et al.*, 2018; Lambrides *et al.*, 2018) Consequently, it is of interest to increase the number of tools for reconstructing fish length and weight from isolated bones, thus allowing the implementation of size analyses of species ubiquitous in the region, such as *Chlorurus microrhinos*, in order to have a better estimate of their role in archaeological assemblages. Live fish length reconstruction may also improve our knowledge of fish population dynamics. Weight and length of fish are currently used as estimators for the evaluation of fisheries and fish resource availability (Kulbicki *et al.*, 2005). Just as weight increases with body length, the length of bone elements also increases with body length, generally according to the degree of allometry, which depends on the species. This should encourage the development of species-level osteometric studies, but few publications cover Indo-Pacific marine species (Leach and Boocock, 1995; Leach *et al.*, 1996a, b; Lidour *et al.*, 2018; Marrast and Béarez, 2019) and only a couple of studies have dealt with scarid osteometry (Rodriguez Santana and Arnay de la Rosa, 1999; Longenecker *et al.*, 2011). In addition to the ecological interest, length and weight estimations allow better understanding of human behaviour related to fishing activities over time. As such, the reconstruction of total body weight is a valuable tool for estimating the significance of specific taxa to the subsistence of ancient populations (Reitz *et al.*, 1987). The reconstructed length classes are indicative of fishing strategies and tools, as well as being informative of exploited fishing grounds, which are respectively based on the relationships between tools and prey-length (Conte, 1988) and between fish-length and its life-history traits and habitats. Here, we propose a predictive model of length and weight reconstruction for *C. microrhinos* from its isolated bones, which could be applied to palaeontological and archaeological studies in the Indo-Pacific area (Bellwood and Schultz, 1991; Longenecker *et al.*, 2014), or stomach content analyses of scarid predators such as moray-eels and sharks. Our goal is also to test the applicability of previous models, established at the sub-family or genus level (Longenecker *et al.*, 2011), to a specific *Chlorurus* species.

MATERIAL AND METHODS

Reconstruction of the length and weight of the fish from its isolated skeletal parts starts with an empirical modelling of modern specimens, of known length and weight, at all stages of growth. In this study, the predictive models follow two steps: first, a regression analysis between bone measurements (BM) and the body length, and second, a regression between the body length and the fresh weight of the fish (Casteel, 1976). The weight could be directly estimated from the bone measurements, but the two-step method allows one

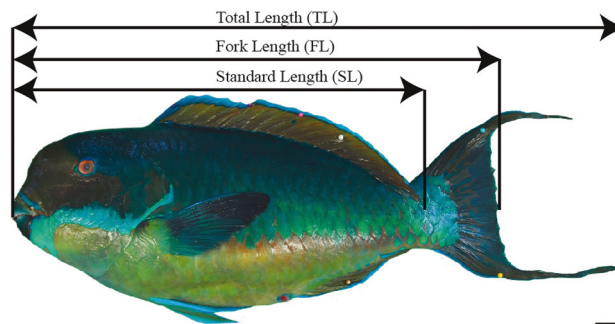


Figure 1. – Picture of a freshly caught *Chlorurus microrhinos* (CIRAP-IC-302, TL = 509 mm, FL = 444 mm, SL = 346 mm, W = 1357 g) showing the different types of length measured. Scale bar = 1 cm.

Table I. – Length and weight measurements of *Chlorurus microrhinos* individuals used to perform the osteometric model (N = 30, W in g; TL, FL and SL in mm).

Collection numbers	W	TL	FL	SL
CIRAP-IC-4	1039	386	361	300
CIRAP-IC-269	1148	432	391	326
CIRAP-IC-274	1216	422	374	328
CIRAP-IC-275	1617	477	396	371
CIRAP-IC-276	1764	503	434	383
CIRAP-IC-277	2198	551	483	417
CIRAP-IC-278	3115	616	517	443
CIRAP-IC-279	1048	421	364	331
CIRAP-IC-280	455	306	288	251
CIRAP-IC-281	1006	407	376	321
CIRAP-IC-282	2300	519	474	413
CIRAP-IC-283	1993	509	453	392
CIRAP-IC-290	304	336	269	254
CIRAP-IC-293	379	341	287	273
CIRAP-IC-294	1114	383	369	312
CIRAP-IC-300	487	285	329	238
CIRAP-IC-301	913	376	346	285
CIRAP-IC-302	1357	509	444	346
CIRAP-IC-303	987	399	360	316
CIRAP-IC-304	772	369	348	306
CIRAP-IC-305	498	293	321	243
CIRAP-IC-306	698	344	326	284
CIRAP-IC-312	3757	639	553	471
CIRAP-IC-313	2690	631	519	447
CIRAP-IC-320	3470	635	555	470
CIRAP-IC-322	2373	589	482	402
CIRAP-IC-342	5341	713	607	512
CIRAP-IC-343	4463	692	601	508
CIRAP-IC-344	5098	696	613	522
CIRAP-IC-345	3513	671	551	474
N Total	30	30	30	30
Minimum	304	285	269	238
Maximum	5341	713	613	522
Mean	1904	482	426	365

to use the existing length-weight relationships available in the literature (Leach and Boocock, 1995).

With the help of professional spear-fishermen, we collected thirty individuals of *Chlorurus microrhinos* in French Polynesian waters (Tahiti, Teti'aroa, Tupua'i and Mangareva islands). Three types of length, i.e. total length (TL), fork length (FL) and standard length (SL) were measured in millimetres (Fig. 1). The weight (W) was measured to the nearest gram (g). Among the individuals collected, TL ranged between 336 and 713 mm while W ranged between 304 and 5341 g (Tab. I). While discussing the use of TL, FL and SL to predict W from skeletal parts, Leach and Boocock (1995) argued that FL should preferably be used based on 1) its common use in modern fisheries, 2) its better preservation and 3) the ease of measurement in fresh fish. According to this proposition, we chose to use FL in our predictive models for body length reconstruction from bone measurements (BM-FL relationships).

Cranial and post-cranial bones were isolated from each specimen after boiling, defleshing and several phases of

water maceration. Bones were then air-dried.

When studying isolated bones in stomach contents or in archaeological and palaeontological contexts, in most cases, jaw bones (+ pharyngeal bones) and vertebrae have a higher likelihood of being found. This study analyzed the skeletal elements commonly found in the archaeological sites of the area: i.e. neurocranium, premaxilla, dentary, maxilla, anguloarticular, quadrate, hyomandibula and upper and lower pharyngeals. The measurements of the bones were performed with a digital calliper to the nearest 0.01 mm.

The modern skeletons collection is housed at the "Centre International de la Recherche Archéologique sur la Polynésie" (CIRAP), University of French Polynesia, Puna'auia, Tahiti.

The bone measurements chosen follow Desse's recommendations (1984). Preferably, all points of measurement should be between the most robust extremities that have a chance to survive in deteriorated contexts. Three kinds of measurement were used in an effort to account for the multidimensional shape of the bones: i.e. the maximal length

Table II. – Description of the bone measurements taken from *Chlorurus microrhinos* skeletal parts, as illustrated in Fig. 2.

Measurement	Abbreviation	Description
Neurocranium M1	Neu M1	Maximal length of the neurocranium, from the rostral tip of the vomer to the caudal extremity of the basioccipital
Neurocranium M2	Neu M2	Maximal height of the neurocranium, from the ventral part of the parasphenoid to the dorsal most part of the supraoccipital crest
Neurocranium M3	Neu M3	Maximal width of the parasphenoid at level of the pharyngeal articulation facets
Premaxilla M1	Pmx M1	Height of the ascending process
Premaxilla M2	Pmx M2	Rostro-caudal length of the dental plate base
Premaxilla M3	Pmx M3	Thickness of the ascending process at mid-height
Dentary M1	Dn M1	Distance from the lower part of the symphysis to the coronoid fossa
Dentary M2	Dn M2	Minimal height of the coronoid process
Dentary M3	Dn M3	Width of the sutures of the symphysis at mid-height
Maxilla M1	Mx M1	Distance from the maxillary head to the caudal process extremity
Maxilla M2	Mx M2	Distance between the maxillary head and the dorsal crest of the maxilla
Maxilla M3	Mx M3	Maximal distance between mesial and premaxillary condyles
Anguloarticular M1	Ar M1	Maximal distance between the rostral tip of the ascending process and the postarticular process
Anguloarticular M2	Ar M2	Distance between the tip of the descending process and the little notch situated between the quadrate facet and the ascending process
Anguloarticular M3	Ar M3	Maximal width of the quadrate facet
Quadrate M1	Qd M1	Length of the preopercular process, from the lateral condyle to its caudal tip
Quadrate M2	Qd M2	Distance from the lateral condyle to the beginning of the ectopterygoid margin
Quadrate M3	Qd M3	Maximal distance between the mesial and the lateral condyles
Hyomandibula M1	Hm M1	Maximal distance between the pterotic and symplectic facets
Hyomandibula M2	Hm M2	Distance between the pterotic facet and the preopercular process
Hyomandibula M3	Hm M3	Mediolateral diameter of the opercular process
Upper Pharyngeal M1	Up. Pha M1	Dorsoventral distance between the cranial condyle and the tooth plate
Upper Pharyngeal M2	Up. Pha M2	Length of the fourth-epibranchial articular condyle
Upper Pharyngeal M3	Up. Pha M3	Width of the alveolar process at the first tooth level
Lower Pharyngeal M1	Low. Pha M1	Maximal width between both tips of pharyngeo-cleithral joints
Lower Pharyngeal M2	Low. Pha M2	Width of the dental plate

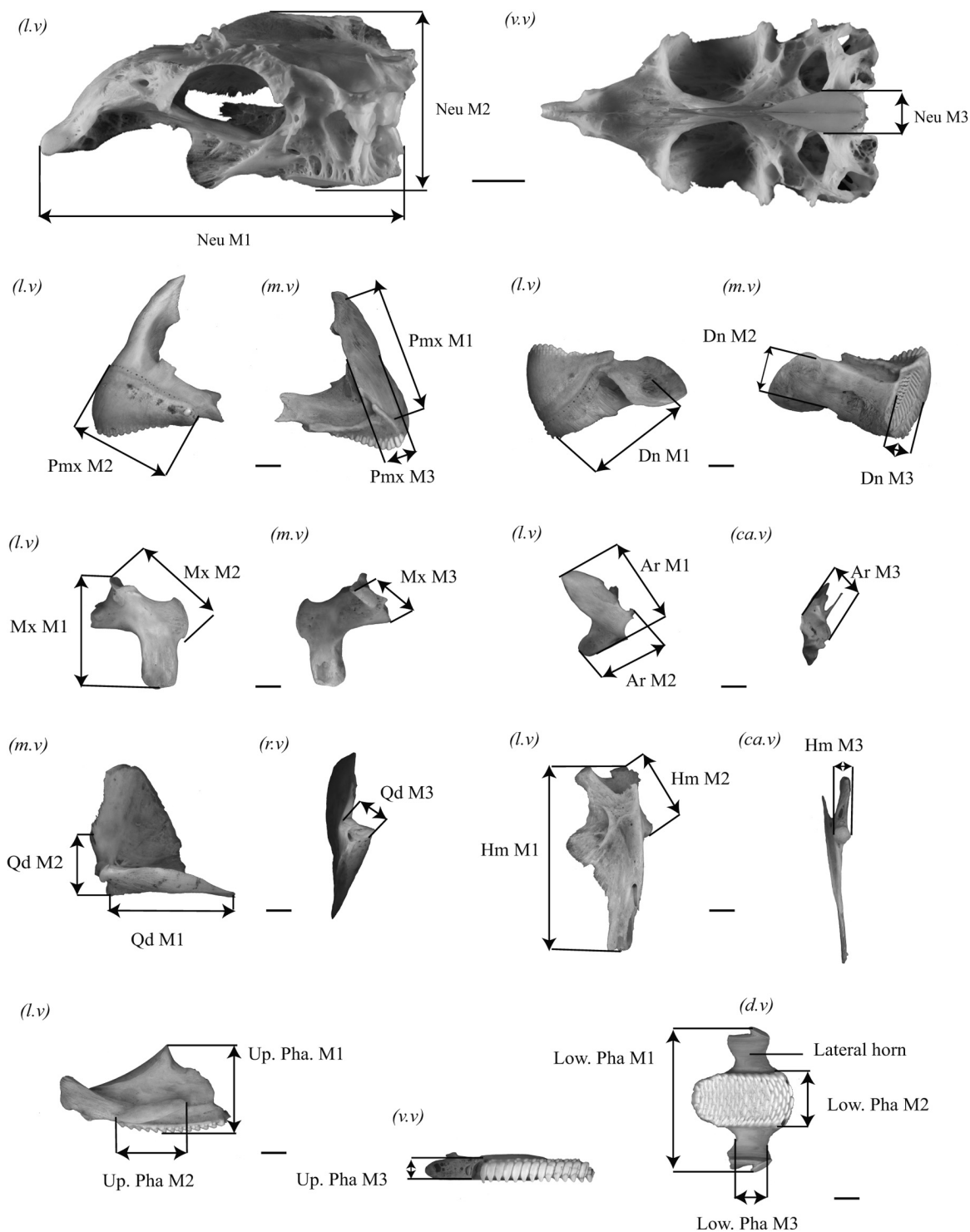


Figure 2. – Position of the osteological measurements taken from *Chlorurus microrhinos*: descriptions of the measurements are given in Table I. Scale bar = 1 cm. Abbreviations: *ca.v.*, caudal view, *d.v.*, dorsal view, *l.v.*, lateral view, *m.v.*, medial view, *r.v.*, rostral view, *v.v.*, ventral view.

(measurement 1, M1), the thickness (measurement 2, M2) and the width (measurement 3, M3). For each bone, all measurements are described and illustrated in Table II and Fig. 2.

Osteological terminology follows that of Bellwood and Choat (1990), Bellwood (1994) and Monod *et al.* (1994).

Length estimation of fish from isolated vertebrae can be

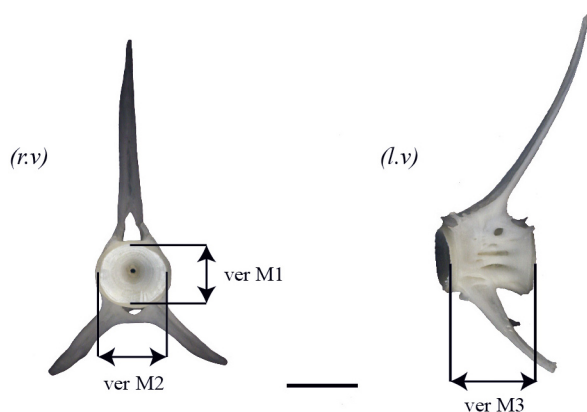


Figure 3. – Vertebra measurements used for the global rachidian profiles of *Chlorurus microrhinos* (CIRAP-IC-277). Abbreviations: ver. M1, M2, M3, vertebrae measurements respectively number 1, 2 and 3. (NB: ver M1, anterior dorsoventral diameter of the centrum; ver M2, anterior mediolateral diameter of the centrum; ver M3, cranio-caudal length of the centrum). Scale bar = 1 cm.

difficult if the rank of the vertebra in the vertebral column cannot be determined (Lambrides and Weisler, 2015). The global rachidian profile (GRP) helps to aggregate vertebrae in homogeneous parts of the rachis depending on species (Desse *et al.*, 1989). Among the three measurements usually taken on vertebrae (Fig. 3), it appeared that the measurement 2 (ver M2) was more reliable and allowed the best aggregations. Aggregation is possible when mediolateral diameter of a group of vertebrae is almost equal, irrespective of the rank. M2 measurements were taken for three specimens at three stages of growth and the respective GRP were obtained. The reconstruction of the length of an individual can then be done visually using the graph (Desse *et al.*, 1989).

The length-length and length-weight relationships of modern fish were determined using the allometric regression model. As for most animals, the growth of each fish body part is relative to its total body length and weight, but with distinct growth rates. This phenomenon, formally described by Huxley and Teissier (1936), is best represented by a power function $Y = aX^b$ where the value Y is the unknown, X the body part measurement, a a constant and b the allometric coefficient. For the length-length and length-weight relationships in fish, a hypothetical value for b for an isometric growth would be $b = 1$ and $b = 3$, respectively, while allometry would be considered positive ($b > 1$ or $b > 3$) or negative ($b < 1$ or $b < 3$).

All length-length relationships (LLR) were derived from bone measurements and fork length (BM-FLR) using the formulae $FL = a (BM)^b$. However, LLR between FL, SL and TL have also been calculated ($TL = a (FL)^b$), as well as length-weight relationship (LWR) between FL or SL and body weight ($W = a (FL)^b$). The quality of the relationship is given by the coefficient of determination (r^2) and the standard error of estimate (SEE) for each of the bone measure-

ments. The best fitted measurements allow reliable estimation of the length and the weight of the fish from its isolated bones.

With the aim of assessing the applicability of our osteometric model to other scarid species, especially in cases where identification of bone remains at species level is not possible, we conducted a test on our modern skeletal collection of *Chlorurus microrhinos* using the equations obtained by Longenecker *et al.* (2011). Their work is based on three species from the Hawaii archipelago: *Chlorurus spilurus* (Valenciennes, 1840), *C. perspicillatus* (Steindachner, 1879), *Scarus dubius* Bennet, 1828. They presented equations for each species, and also proposed a general equation for higher taxa: *Chlorurus* genus and Scarinae. We followed the description of their points of measurement on selected head bones (premaxilla, dentary, anguloarticular, upper and lower pharyngeals), and made a graphic representation of the results.

RESULTS

The relationships between different types of body length (LLR) showed positive allometries (Tab. III), which indicate a faster growth of SL against FL but also a faster growth of SL and FL against TL. The length-weight relationship (LWR) also revealed positive allometry for FL and SL relative to W (Tab. III), indicating a faster growth in length than in weight. The use of FL and SL to estimate TL was found to be reliable, as was the use of TL, FL and SL to predict W ($r^2 > 0.9$).

The BM-FL relationships showed strong correlations ($r^2 > 0.9$) except for premaxilla M3 and lower pharyngeal M1 with SEE ranging between 13.97-32.95 (Tab. IV).

Among the three measurements taken on vertebrae, the mediolateral diameter at the anterior extremity (M2) was better correlated to the body length. Its value for the 24 centra (urostyle not included) recorded in three individuals of *Chlorurus microrhinos* are plotted in Fig. 4. The obtained GPR for specimens A, B and C allow aggregation of the vertebrae in two regional groups. We observed a heterogeneous

Table III. – Length to length and length to weight equation parameters obtained for *Chlorurus microrhinos* (N = 30, length in mm, W in g).

Formula $Y = aX^b$	a	b	r^2
Length-length relationship (LLR)			
$TL = a SL^b$	0.4996	1.1638	0.9779
$TL = a FL^b$	0.5203	1.1277	0.9749
$FL = a SL^b$	1.0165	1.0231	0.9859
Length-weight relationship (LWR)			
$W = a FL^b$	3.36E-06	3.2960	0.9732
$W = a SL^b$	6.4E-06	3.2742	0.9584

Table IV. – Regression formulae parameters for estimating the fork length of *Chlorurus microrhinos* from bone measurements (in mm). (NB: some bones can be deteriorated during the osteological preparation; hence the number of measured specimens can be lower than the total number of individuals). * SEE: standard error of estimate.

Bone measurement (BM)	Formula FL = a (BM) ^b				
	a	b	r ²	N	SEE*
Neurocranium M1	4.533	1.0422	0.9764	29	15.44
Neurocranium M2	16.811	0.8672	0.977	30	15.32
Neurocranium M3	40.36	0.9861	0.9322	29	28.42
Premaxilla M1	10.065	1.0283	0.91	30	23.49
Premaxilla M2	23.259	0.9057	0.922	30	21.99
Premaxilla M3	50.066	0.9704	0.8707	30	27.65
Dentary M1	29.318	0.8297	0.9796	30	15.87
Dentary M2	43.781	0.8443	0.9421	30	24.17
Dentary M3	54.571	0.9759	0.948	30	23.39
Maxilla M1	17.105	0.9563	0.9747	30	16.98
Maxilla M2	21.346	0.9541	0.973	30	18.82
Maxilla M3	35.018	0.9274	0.9592	30	20.05
Anguloarticular M1	26.222	0.9327	0.9557	27	21.37
Anguloarticular M2	52.258	0.7735	0.968	27	18.42
Anguloarticular M3	67.949	0.8589	0.9257	27	26.72
Quadrates M1	11.902	1.0114	0.9602	29	18.92
Quadrates M2	58.313	0.7406	0.9084	29	32.96
Quadrates M3	66.832	0.8783	0.9292	29	27.33
Hyomandibula M1	8.697	1.0108	0.9799	30	13.97
Hyomandibula M2	19.102	0.9767	0.9716	30	17.79
Hyomandibula M3	101.77	0.9832	0.9285	30	30.66
Upper pharyngeal M1	20.947	0.9598	0.9343	28	27.15
Upper pharyngeal M2	30.921	0.9389	0.9235	28	31.33
Upper pharyngeal M3	69.353	1.0064	0.9559	28	21.87
Lower pharyngeal M1	17.877	0.8866	0.8859	29	29.96
Lower pharyngeal M2	28.33	1.0099	0.9155	29	29.39
Lower pharyngeal M3	80.359	0.8542	0.9198	29	30.66

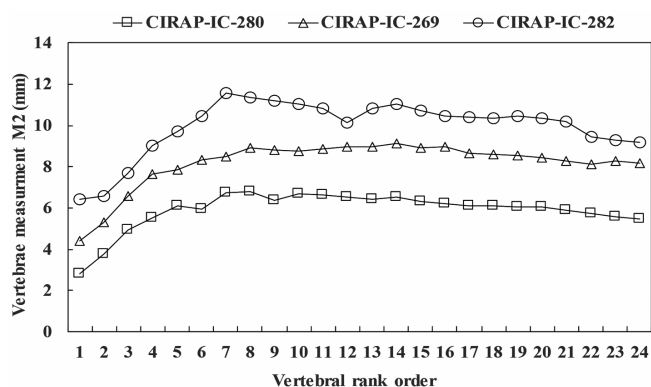


Figure 4. – Global rachidian profiles obtained from three individuals of *Chlorurus microrhinos*: CIRAP-IC- 280 (FL = 288 mm), CIRAP-IC-269 (FL = 391 mm) and CIRAP-IC-282 (FL = 474 mm).

precaudal part from the first to the seventh precaudal vertebrae, and a homogeneous part from the eighth vertebral rank

to the 24th. The variability of the M2 measurement shows the necessity to know the rank of the vertebrae of the first group prior to their use for estimation of the FL. The quasi-equal M2 values of the vertebrae of the second group enables the use of their measurement without knowing their exact rank in the rachis.

In order to test the validity of the osteometric model established for Hawaiian *Chlorurus* species by Longenecker *et al.* (2011), we made measurements on the premaxillae of individuals from our reference collection of *Chlorurus microrhinos* according to their protocol and applied their regression equations. We present and discuss here the values obtained for the reconstruction of length and weight from premaxilla measurements (Fig. 5).

Discrepancies are quite important, with length and weight being largely overestimated in small individuals, and partly underestimated in large individuals. This could be due to morphological differences between *Chlorurus* congeners but could also be due to the choice of the osteometric model parameters. Longenecker *et al.* (2011) used TL, which is often difficult to measure, and used linear models instead of allometric models.

DISCUSSION AND CONCLUSION

The LWR investigated have allometric coefficients ranging between 2.5 and 3.5, as is usually the case (Froese, 2006). When we compare our LWR with previously published data (Tab. V), our SL to W and FL to W are different, except the positive allometry for FL to W, similar to that of Kamikawa *et al.* (2015).

According to Froese (2006), the value *b* can first be influenced by the sample size, in particular by the length range covered by all individuals, but also by the variability in body proportions between small and large specimens. Body proportions depend in part on the nutritional condition of each fish at the time of the catch, which in turn is influenced by food availability in the local habitat. This specifically highlights the variability of the *b* value through seasonal and interannual cycles, and geographically, aspects that we did not explore for French Polynesian waters. Nevertheless, the relationship between bone measurements and body-length can be applied. In most cases, bone measurements exhibit a strong correlation with FL of *Chlorurus microrhinos*, which allows the use of regression equations for reliable estimation of FL from isolated bones. However, lower correlation coefficients reveal the low accuracy of other measurements, as is the case for quadrate M2 and lower pharyngeal M1 – which were noted but not explored further in relation to intra-specific variability in osteological growth. The variability of measurements might be due in part to the plasticity of bone during growth, with some discrete characters being

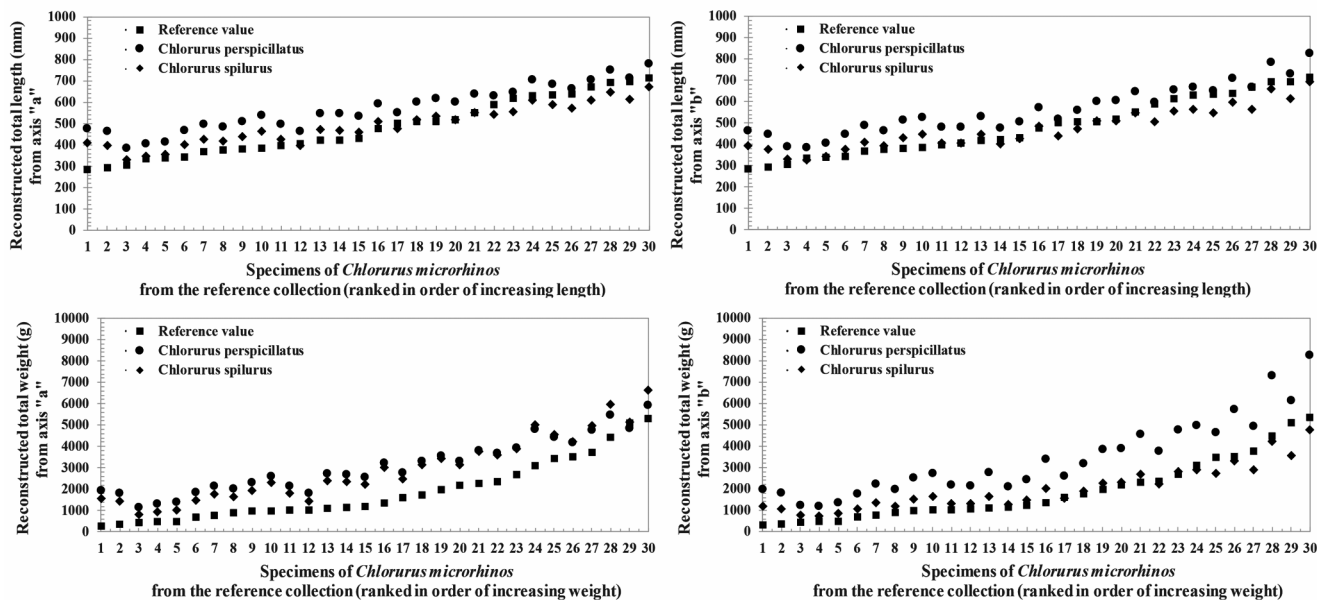


Figure 5. – Reconstruction of the length and weight of individuals of the *Chlorurus microrhinos* reference collection using the two measurements (“axis a” and “axis b”) of the premaxilla as defined by Longenecker *et al.* (2011) for *C. perspicillatus* and *C. spilurus*.

Table V. – Length to weight equation parameters for *Chlorurus microrhinos* from other areas (converted from published data). (Length in mm).

Geographic area	Reference	Length	min L	max L	a	b	r ²	N
Lizard Is, Australia	Choat <i>et al.</i> , 1996	SL	105	494	9.25E-05	2.85	0.974	85
New Caledonia	Letourneur <i>et al.</i> , 1998	FL	40	530	3.21E-05	2.93	0.998	21
Guam	Kamikawa <i>et al.</i> , 2015	FL	197	497	1.48E-05	3.07	0.99	1053

more conspicuous in smaller individuals than in larger ones, or vice versa.

Osteometric models are efficient tools for length reconstruction of fish, especially when they are species-specific and cover a wide range of individual lengths and weights. The present work attempts to participate to the global initiative launched by Desse (1984) by providing new data on a common species of scarid, which will likely be of use to biologists and archaeozoologists working with parrotfish species in the Pacific region. However, future work should include more skeletal elements, as well as otoliths, as they are systematically found in the area since the recent implementation of fine mesh screening during archaeological fieldwork (Weisler, 1993).

Acknowledgements. – We would like to thank all the fishermen for catching and donating the fish for use in this study. We also thank René Galzin and the “Centre de Recherches Insulaires et Observatoire de l’Environnement” (CRIOBE) based at Mo’orea for their support, the identification of species and their help in the preparation of the skeletons. Thanks to Saskia Ryan for editing the text. This work was supported by funds from the “Centre International de la Recherche Archéologique sur la Polynésie” (CIRAP) and the LabEx Corail.

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