An osteometric approach to reconstruct the length and weight of *Lutjanus argentiventris* (Perciformes: Lujtanidae) for archaeological and ecological purposes

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Lutjanus argentiventris presents a large intertropical distribution within the Eastern Pacific, which is as important to fisheries now as it was in the pre-Hispanic period. The purpose of this article is to present an allometric model that enables the size and weight of *L. argentiventris* to be predicted, using the isolated bones found in archaeological and paleontological contexts or the stomach contents of ichthyophagous species. A modern collection of *L. argentiventris* from Ecuador was used, composed of 37 individuals covering a wide range of sizes and weights. The total length (TL), standard length (SL), and total fresh weight (W) of each individual was gathered. The TL of the sample ranged between 210 and 760 mm, the SL between 164 and 627 mm and the W ranged between 123 and 6550 g. The most frequent bones (15) and otoliths were chosen and 39 measurements were taken. The total length-weight relationship was $W = 6E\text{-}06\ TL^{3.1513}$ with $R^2 = 0.997$. In general, it was observed that the relationships between the TL and the bone measurements had a strong correlation ($R^2 > 0.95$). The allometric model will be useful not only for archaeologists but also for biologists working on historical ecology.

Keywords: Allometry, Ichthyoarchaeology, Osteometry, Tropical Eastern Pacific, Length-weight relationship.

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Lutjanus argentiventris presenta una distribución intertropical en el Pacífico Oriental, siendo una especie importante desde épocas prehispánicas hasta la actualidad. El propósito de este artículo es presentar un modelo alométrico que prediga la talla y el peso de *L. argentiventris*, usando restos óseos aislados encontrados en contextos arqueológicos y paleontológicos. Se empleó una colección de 37 individuos con tallas y pesos variados, provenientes del Ecuador. La longitud total (LT), la longitud estándar (LE) y el peso (P) de cada individuo fueron recolectados. La LT varió entre 210 y 760 mm, la LE entre 164 y 627 mm y el P entre 123 y 6550 g. Se escogieron los huesos más frecuentes (15) y los otolitos para realizar 39 mediciones. La relación de la longitud total y el peso fue P = 6E-06 $TL^{3,1513}$ con un valor de R^2 = 0,997. En términos generales se observa que las relaciones entre la LT y las medidas de los huesos presentan una correlación fuerte (R^2 > 0,95). El modelo alométrico presentado puede utilizarse para predecir el tamaño y el peso, no sólo de *L. argentiventris*, sino también de sus congéneres, y será útil para arqueólogos y biólogos interesados en ecología histórica.

Palabras clave: Alometría, Ictioarqueología, Osteometría, Pacífico Oriental Tropical, Relación longitud-peso.

INTRODUCTION

The Lutjanidae family consists of 17 genera and 112 species, which are distributed in tropical and subtropical seas worldwide, but mostly in the Indo-Pacific (Fricke *et al*., 2020). The genus *Lutjanus* Bloch, 1790 is by far the most speciose, containing 73 species, including nine in the Eastern Pacific: *Lutjanus aratus* (Günther, 1864); *L. argentiventris* (Peters, 1869); *L. colorado* Jordan, Gilbert, 1882; *L. guttatus* (Steindachner, 1869); *L. inermis* (Peters, 1869), *L. jordani* (Gilbert, 1898); *L. novemfasciatus* Gill, 1862; *L. peru* Nichols, Murphy, 1922; and *L. viridis* (Valenciennes, 1846). The maximum total length (TL) of these species ranges between 300 mm (*L. viridis*) and 1700 mm (*L. novemfasciatus*) (Allen, 1985, 1995).

Snappers are important resources to artisanal and commercial fisheries worldwide, with the biggest catches in the Western Central Pacific and Western Central Atlantic (Allen, 1985; Salas *et al*., 2011). In the Tropical Eastern Pacific (TEP), the catch is less, however *L. argentiventris* is an important species for small-scale fisheries (*e.g.* Alava *et al*., 2015). In Mexico, the annual landings of the artisanal fleet have oscillated between 0.5 and 1.5 t (Espino-Barr *et al*., 2004). A long-term study (1983–1998) of artisanal marine fisheries in Colima, Mexico, shows that *L. argentiventris* is the seventh most abundant species in the region's catches (Espino-Barr *et al*., 2002). At Bahia de Navidad, Jalisco, Mexico, another study, covering 47 months (5 days per month in 1994–1995 / 1998–2000) reveals that ten species accounted for more than 60% of the total abundance and biomass, with *L. argentiventris* in eighth place (Rojo-Vázquez *et al*., 2008). In the southwestern Gulf of California, Mexico, *L. argentiventris* is among the eight most commercially important reef fishes (Erisman *et al*., 2010). It is normally captured using various types of craft nets, gillnets, harpoons, and hook-and-lines (Rojas *et al*., 2004; Lucano-Ramírez *et al*., 2014).

The archaeological record shows the importance of the species along the Pacific coast for millennia. In Mexico, archaeo-ichthyological samples from the site of Huatabampo (Sonora) exhibit high numbers (Number of identified specimens [NISP] = 106; Minimum number of individuals [MNI] = 10) of snappers (*Lutjanus* cf. *argentiventris*). The presence of this species suggests that the ancient inhabitants of Huatabampo were fishing in areas with a strong marine influence (Guzmán, 2008). In Panama, snappers are present in the archaeological material of Cerro Mangote (Cooke, Ranere, 1999) and, more commonly, in the Pearl Islands archipelago, in Pedro Gonzalez (Cooke, Jiménez, 2009) and Bayoneta Island (Martínez-Polanco *et al*., 2009). Pre-Ceramic occupations at Pedro Gonzalez (4030–3630 BC) and Ceramic occupations at Bayoneta Island (*ca*. 900 and 1300 AD) fishing data suggest that snappers were taken with similar frequency during both time periods (Cooke, Jimenez-Acosta, 2009; Martínez-Polanco *et al*., 2009). Snappers are evenly distributed in low numbers in Ecuadorian sites (*e.g.* Béarez, 1996; Béarez *et al*., 2012).

Just as the weight increases with the size of the fish, bone size also increases with body size. The growth rate of each body part varies depending on species ontogeny and morphology (Teissier, 1948). In archaeology, fish body size and weight are used to study human diet, and to infer on fishing strategies and techniques, human exploitation and the overexploitation of fish faunas (*e.g.* Reitz *et al*., 1987; Lambrides, Weisler, 2015; Thieren, Van Neer, 2016; Prestes-Carneiro, Béarez, 2017; Lidour *et al*., 2018; Rurua *et al*., 2020). In particular, some aspects of fishing can be studied in depth: (1) changes in the geographic ranges of species, (2) reductions in their abundances, (3) signatures of trophic cascades and (4) marine fisheries trophic level changes (Erlandson, Rick, 2010).

On the other hand, Karachle, Stergiou (2012) summarize the importance of length-weight models in three aspects of modern ecology studies: (1) use of length data as an estimation of biomass; (2) to ascertain the condition of the species; and (3) to compare the life history of different populations of the same species. In fisheries management, the weight and the size of fish are used to estimate population parameters, life history characteristics and to develop programs for the protection and management of the species (Castellanos-Galindo, Zapata-Padilla, 2019). This kind of information could be used to determine the minimum permissible lengths of capture and identification of suitable periods for a closed fishing season. The identification of age-classes and male to female ratios are relevant to evaluate the status of an exploited stock and to establish future harvest levels, and the relationship between fish-size and its life-history traits and habitats (Castellanos-Galindo, Zapata-Padilla, 2019; Froese, Pauly, 2019).

In modern fisheries, the concept of baseline is understood as the fish population that was present before human influence (Pauly, 1995). This author addresses the shifting baseline syndrome, but this can only be resolved by developing a pre-industrial baseline that extends beyond the origins of modern fishing, both artisanal and commercial (Froyd, Willis, 2008; Betts *et al*., 2011, 2014; Barrett, 2019). Baselines should not assume static environments but rather dynamic systems (Rick, Lockwood, 2012). It is in this point where zooarchaeology and particularly ichthyoarchaeology can contribute with information to manage modern fisheries (Betts *et al*., 2011, 2014; Barrett, 2019). Fish size comparison between modern, historical and archaeological data could be used to regulate marine protected areas and to propose clear conservation objectives. For example, if archaeological data are used as baselines, new indicators could be proposed, and compared over time. Similarly, reference levels of objectives, thresholds or limits could be developed to inform the management of marine resources and ecosystems (Schwerdtner-Máñez *et al*., 2014). At the same time, it could determine the absolute magnitude of the changes that can occur in a heavily exploited fish stock. Analysis of long-term trends in fish size can provide a key indicator of changes in ecological baselines (Betts *et al*., 2011, 2014; Barrett, 2019). Other contributions of the study of the archaeological fish size are to measure fluctuations in the aquatic environment and the intensity of exploitation (Betts *et al.,* 2011, 2014; Barrett, 2019).

In this article, the attention will focus on the yellow snapper, *L. argentiventris*, which has a subtropical distribution, ranging in the Eastern Pacific from southern California to northern Peru, including the Galapagos Islands (Allen, 1985) (Fig. 1). The species is found in coral and rocky reefs at a depth range of 3–60 m and also in estuaries and river mouths, being tolerant to freshwater. It is characterized by a pinkish red colour of the anterior part of the body, which becomes bright orange to yellow in its posterior part. The fins are mainly yellow or orange. The yellow snapper is an active predator, feeding mainly at night on fish, shrimp, crabs and mollusks (Allen, 1985). Individuals can form small aggregations during the day or shelter in caves. The species also form seasonal spawning aggregations, a trait that makes many species vulnerable to overfishing (Sala *et al*., 2003). The species has been recorded up to a TL of 760 mm and a maximum weight (W) of 6550 g (Béarez, 1996: 44). For Gorgona Island in Colombia, Rojas *et al.* (2004) reported that the average size at sexual maturity was 515 mm TL and that the length-weight relationships were not significantly different between sexes. In the case of the central Mexican Pacific, the size range at sexual maturity was 260–330 mm for females and 240–320 mm for males (Lucano-Ramírez *et al*., 2014).

Our purpose is to present an allometric model that enables the length and weight of *Lutjanus argentiventris* to be predicted, using the isolated bones from archaeological and paleontological contexts or the stomach contents of ichthyophagous species. Length-weight relationships for *L. argentiventris* can be found for Mexico (González *et al*., 2004; Aburto-Oropeza *et al*., 2009; García-Contreras *et al.,* 2009; Piñón *et al*., 2009; Velázquez-Velázquez *et al*., 2009), Panama (Bonilla-Gómez *et al*., 2014) and Colombia (Rojas *et al*., 2004) but not for Ecuador. As there is no information available for the southernmost part of the range of *L. argentiventris*, it is useful to check whether this relationship is similar or different from those already known in more northern countries. Rojas *et al.* (2004) reported that the species is moderately slow growing, appears to be long-lived and has a low natural mortality rate, making it easily vulnerable to overfishing. It is therefore important to build osteometric models that could be used for in-depth long-term studies of *L. argentiventris* populations, with the aim of proposing management strategies.

MATERIAL AND METHODS

All the skeletons came from the fish collection of the Muséum national d'histoire naturelle in Paris. The modern collection of *Lutjanus argentiventris* is composed of 37 individuals covering a wide range of sizes and weights: 36 are from Ecuador and one is from Panama. The TL of the sample ranged between 210 and 760 mm, and the SL between 164 and 627 mm. The W ranged between 123 and 6550 g. The fish from

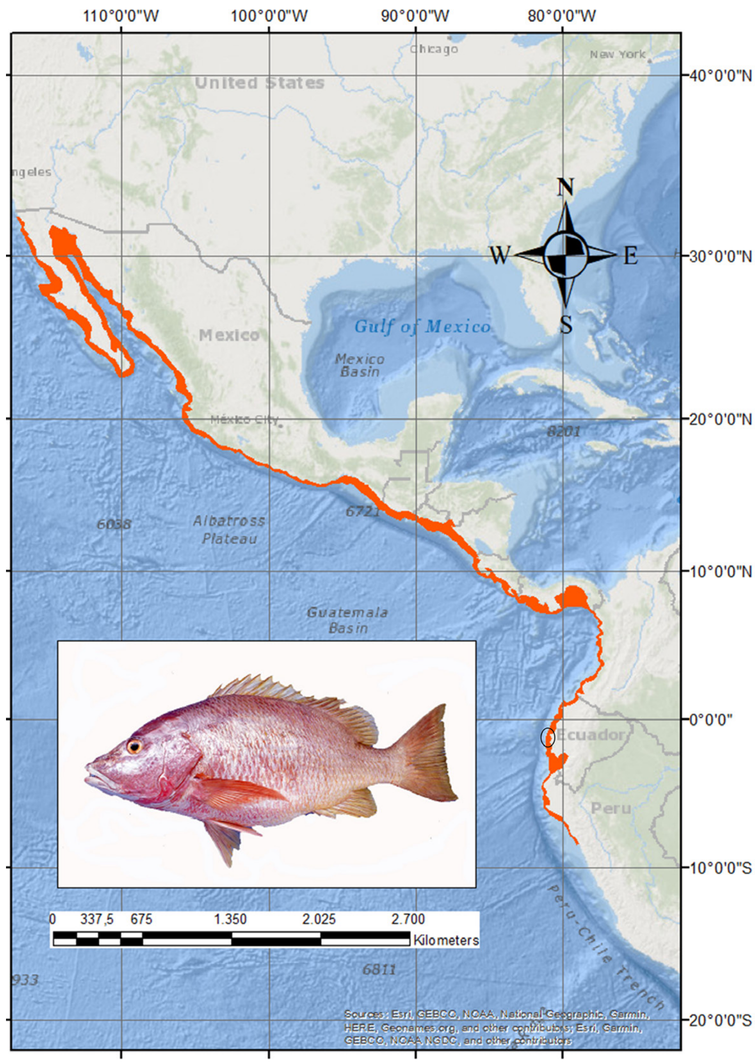

FIGURE 1 | *Lutjanus argentiventris* geographical distribution (Map adapted from Robertson, Allen, 2015; Image represents a 645 mm TL individual).

Ecuador (MNHN-ICOS-1776 to -1811) were sampled between 1992 and 1998 in the vicinity of Puerto López (Fig. 1) mostly over rocky reefs, and using harpoons. The specimen from Panama (MNHN-ICOS-1812) was sampled at Isla del Rey (Pearl Island Archipelago) in 2000. All individuals have complete information about their total length (TL) and standard length (SL), which were recorded in millimeters (mm), and their total fresh weight (W) in grams (g).

Specimens from other *Lutjanus* species were also used, such as: *L. novemfasciatus* (n = 3); *L. colorado* (n = 1); *L. peru* (n = 1); *L. guttatus* (n = 4) and *L. argentimaculatus* (n = 1). These specimens were also collected from the same locations and at the same time period as *L. argentiventris*, except for the last one which comes from Kenya (Indian Ocean). For this study, all the specimens were used, including the Panamanian specimen and the other species individuals, to test the model. We included other species because in the archaeological record it is sometimes very difficult to arrive at a species level determination, at times we only succeed to determine the genus, which is quite often the case within the genus *Lutjanus* (*e.g.* Guzmán, 2008).

Among the most frequently preserved bones in the archaeological archives, 15 were selected, 39 measurements were taken, and otoliths were included (Tab. 1, Fig. 2). Measuring points were chosen in such a way that they had a good probability of being found among archaeological remains; for this reason, the slender and fragile parts were discarded and the robust parts were preferred (Desse, 1984). The measurements were taken using a digital caliper with a precision of two decimal points. Following convention, the left side bones were measured. However, in the case of the otoliths, both sagittae (left and right) were measured and a two-sample (paired samples) *t-test* was performed in order to identify eventual differences between sides (the null hypothesis being that the means of two populations are equal).

An allometric regression model was employed to determine the length-length and length-weight relationships for the *L. argentiventris* collection. This model assumes that the growth of each body part is relative to its total body length and weight, but with distinct growth rates (Teissier, 1948; Reitz *et al*., 1987; Marean *et al*., 2001). The length-weight relationship is represented by a power function:

$$Y= aX^{b}$$

Where "Y" is the total weight of the fish, "X" is the total length, "a" a constant and "b" the allometric coefficient. To create this model, we also used 11 more specimen data (TL, SL, W) measured in Ecuador from fresh fishes that could not be preserved. The total sample was 48 (37 collected and preserved fishes + 11 fresh fishes not preserved).

In the case of the length-length relationships the same function was used; however, "Y" is the total length, and "X" is the body part measurement. The quality of the relationship is given by the coefficient of determination (R^2). The best fitted measurements allowed us to reliably estimate the length and the weight of the fish from its isolated bones.

Desse *et al.* (1989) proposed to establish Global Rachidian Profiles (GRP) to identify the position of the vertebrae along the spine. This approach is really helpful in archaeological cases where the vertebrae are the most common element. At the same time, by knowing the height of an archaeological vertebra it is possible to estimate the size of an individual. To construct the GRP of *L. argentiventris,* four individuals with different sizes were selected, and measurements were taken on the caudal (diameters M1 and M2) and ventral faces (M3) of the vertebrae (Tab. 1, Fig. 2).

RESULTS

The total length-weight relationships reflected a slight allometric growth (b = 3.1513), with a high coefficient of determination (R^2 = 0.997) (Tab. 2, Fig. 3).

In general, it was observed that the relationships had a strong correlation (R^2 > 0.95) (see Tab. 1, Fig. 2 for bone measurements). The measurements relating to the maximal length of the element were well correlated with the TL. However, other measurements, based on small parts of the bones, which are the most frequently preserved, were also well correlated (see Fig. 4 for other *Lutjanus* species and the Panamanian specimen).

TABLE 1 | *Lutjanus argentiventris* bone measurements descriptions (see also Fig. 2).

Measurement	Abbrev.	Description
Vomer M1	Vo M1	Maximal mediolateral width of the vomer
Basioccipital M1	Boc M1	Maximal width of the articular surface of the basioccipital
Basioccipital M2	Boc M2	Maximal height of the articular surface of the basioccipital
Premaxilla M1	Pmx M1	Maximal length of the premaxilla
Premaxilla M2	Pmx M2	Rostro-caudal length of the basis of combined ascending and articular processes
Premaxilla M3	Pmx M3	Thickness of the ascending process at mid-height distance from the lower part of the symphysis to the coronid fossa
Dentary M1	Dn M1	Maximal length, from the rostral tip of the dentary to the caudal tips of the coronoid and ventral processes
Dentary M2	Dn M2	Height of the symphysis
Dentary M3	Dn M3	Maximal width of the rostral extremity
Maxilla M1	Mx M1	Maximal length of the maxilla, from the rostral tip of the external process to the tip of the caudal processes
Maxilla M2	Mx M2	Maximal width of the dorsal condyle
Maxilla M3	Mx M3	Medio-lateral width at posterior level of the dorsal process
Anguloarticular M1	Ang M1	Maximal length between the line joining the quadrate facet and the post-articular process and the rostral tip of the anterior process
Anguloarticular M2	Ang M2	Distance between the cranio-ventral tip and the little notch situated between the quadrate facet and the post-articular process
Anguloarticular M3	Ang M3	Maximal width of the quadrate facet
Quadrate M1	Qd M1	Distance between the tip of the mesial condyle and the tip of the preopercular process
Quadrate M2	Qd M2	Distance between the ventral tip of the mesial condyle and the dorsal tip of the ectopterygoid margin
Quadrate M3	Qd M3	Distance between the external tip of the lateral condyle and the internal tip of the mesial condyle
Palatine M1	Pal M1	Maximal length of the palatine, Dorso-ventral diameter of the anterior (maxillary) process (M3)
Palatine M2	Pal M2	Distance between the recess situated in the condyle coiling and the cranial tip of the maxilla process
Palatine M3	Pal M3	Distance between the median recess of the dorsal edge and the posteroventral base of the anterior (maxillary) process (M2)
Hyomandibula M1	Hm M1	Distance between the symplectic facet and the line joining the tips of the sphenotic and pterotic facets
Hyomandibula M2	Hm M2	Distance between the sphenotic facet and the opercular process
Hyomandibula M3	Hm M3	Distance between the ventral bases of the pterotic facet and the opercular process
Preopercle M1	Pop M1	Maximal length of the preopercle
Preopercle M2	Pop M2	Distance between the anterior margin and the median notch of the posterior margin
Preopercle M3	Pop M3	Maximal thickness of the quadrate crest
Opercle M1	Op M1	Distance from the supra-articular process to the ventral extremity of the opercle
Opercle M2	Op M2	Height of the articular fossa
Opercle M3	Op M3	Cranio-caudal length of the articular fossa
Post-temporal M1	Ptp M1	Distance between the tip of the dorsal process and the articular facet
Post-temporal M2	Ptp M2	Distance between the tip of the ventral process and the articular facet
Supracleithrum M1	Spcl M1	Maximal length of the supracleithrum
Supracleithrum M2	Spcl M2	Maximal thickness of the supracleithrum in its median part
Cleithrum M1	Cl M1	Maximal length of the cleithrum
Cleithrum M2	Cl M2	Distance between the tip of the anterodorsal process and the scapula joint
Cleithrum M3	Cl M3	Width of the cleithrum at level of the posterodorsal notch
Otolith sagitta M1	Oto M1	Maximal length (rostro-caudal axis)
Otolith sagitta M2	Oto M2	Maximal height (dorso-ventral axis)

Regarding the GRP, four M2 profiles from four individuals are represented in Fig. 5A, and profiles for the M1, M2 and M3 of a single individual are represented in Fig. 5B. In both figures, two main zones could be distinguished: the anterior zone from

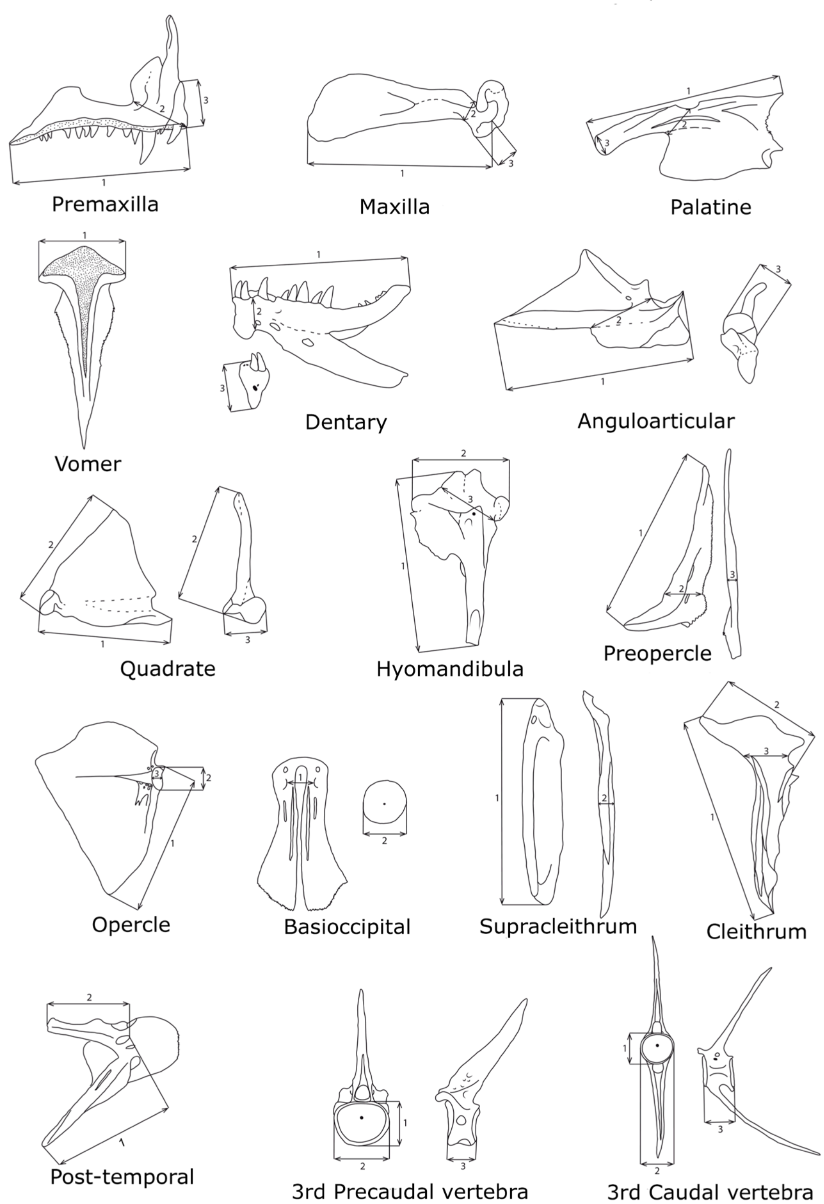

FIGURE 2 | *Lutjanus argentiventris* bone measurements.

vertebrae 1 to 7, and the posterior zone from vertebrae 8 to 24. The anterior zone is more heterogeneous while the posterior zone is more homogeneous.

In the case of the otoliths, it was observed that the exponent of the allometric equation was superior to 1 (Tab. 2). This implies that they grow more slowly than the rest of the body. There were no significant differences between the length, height and weight of the right and left otoliths (Tab. 3).

Some degree of similarity was observed between the "b" values of the length-weight relationship obtained in this study and those from previous studies from Mexico, Panama and Colombia (Tab. 4). These results indicate that *Lutjanus argentiventris* has a similar, often isometric, growth all along its range.

TABLE 2 | *Lutjanus argentiventris* length to length and length to weight equation parameters (Length in mm and weight in g) (n = 37).

Body element	Measurement	n	Mean	SD	Min.	Max.	Relationship	a	b	R	r2
Standard length		48	362.27	133.58	164.00	627.00	TL *vs.* SL	0.84110	17.71600	0.998	0.999
Total length		48	451.75	160.01	210.00	760.00	W *vs.* TL	0.00001	3.15130	0.997	0.999
Weight		47	1902.43	1794.05	123.00	6550.00	W *vs.* SL	0.00003	3.00870	0.996	0.998
Vomer	1	34	12.86	4.91	6.52	25.33	vo M1 *vs.* TL	36.46500	0.94810	0.980	0.990
Basioccipital	1	35	3.66	1.46	1.78	8.21	boc M1 *vs.* TL	127.57000	0.89530	0.906	0.952
	2	35	7.17	3.46	3.37	16.73	boc M2 *vs.* TL	89.47600	0.77720	0.965	0.982
Premaxilla	1	36	30.77	12.27	15.84	61.97	pm M1 *vs.* TL	16.45600	0.93400	0.995	0.998
	2	36	9.36	4.18	4.58	20.53	pm M2 *vs.* TL	60.46500	0.85200	0.981	0.991
	3	36	7.10	3.61	2.78	17.71	pm M3 *vs.* TL	94.61600	0.74790	0.956	0.978
Dentary	1	36	32.23	12.01	16.80	63.02	dn M1 *vs.* TL	13.06600	0.98690	0.996	0.998
	2	36	6.77	3.08	3.22	14.35	dn M2 *vs.* TL	85.51900	0.81810	0.986	0.993
	3	36	19.41	7.03	10.40	33.19	dn M3 *vs.* TL	20.21900	1.00760	0.979	0.989
Maxilla	1	36	35.05	13.95	17.85	71.75	mx M1 *vs.* TL	14.30200	0.93920	0.996	0.998
	2	36	5.22	2.46	2.23	11.69	mx M2 *vs.* TL	111.30000	0.78710	0.984	0.992
	3	36	6.78	2.78	3.54	15.48	mx M3 *vs.* TL	68.77500	0.92470	0.968	0.984
Anguloarticular	1	35	36.35	13.11	18.80	66.73	ar M1 *vs.* TL	10.52800	1.01500	0.995	0.997
	2	35	12.97	4.95	6.27	23.11	ar M2 *vs.* TL	35.52900	0.94980	0.985	0.992
	3	35	5.97	2.99	2.68	15.26	ar M3 *vs.* TL	101.64000	0.78360	0.984	0.992
Quadrate	1	36	24.05	8.77	12.53	45.31	qd M1 *vs.* TL	16.23600	1.00900	0.994	0.997
	2	36	20.41	8.70	10.28	41.48	qd M2 *vs.* TL	28.70700	0.87800	0.988	0.994
	3	36	6.63	2.94	3.32	14.36	qd M3 *vs.* TL	79.06500	0.86520	0.987	0.994
Palatine	1	36	26.87	10.26	13.89	52.15	pl M1 *vs.* TL	16.88700	0.96390	0.994	0.997
	2	36	5.78	2.47	2.87	12.51	pl M2 *vs.* TL	86.18100	0.88170	0.963	0.981
	3	36	1.59	0.81	0.75	3.62	pl M3 *vs.* TL	290.91000	0.74100	0.924	0.961
Hyomandibula	1	36	33.54	13.34	17.14	67.32	hm M1 *vs.* TL	14.95100	0.93840	0.993	0.996
	2	36	18.10	7.35	8.96	36.47	hm M2 *vs.* TL	28.66100	0.91400	0.992	0.996
	3	36	12.96	5.17	6.32	25.86	hm M3 *vs.* TL	41.47900	0.88100	0.949	0.974
Preopercle	1	36	57.29	22.37	29.12	112.08	pop M1 *vs* TL	8.85350	0.94350	0.997	0.998
	2	36	12.55	5.27	6.70	24.74	pop M2 *vs.* TL	42.64300	0.88920	0.951	0.975
	3	36	2.98	1.55	1.40	7.39	pop M3 *vs.* TL	183.24000	0.73870	0.941	0.970
Opercle	1	36	34.70	14.59	17.27	68.15	op M1 *vs.* TL	17.21400	0.89060	0.990	0.995
	2	36	5.26	2.38	2.32	12.17	op M2 *vs.* TL	100.66000	0.84070	0.962	0.981
	3	36	4.72	1.93	2.54	9.39	op M3 *vs.* TL	97.03600	0.91910	0.958	0.979
Post-temporal	1	36	21.31	8.26	11.16	40.22	ptp M1 *vs.* TL	21.78000	0.95400	0.989	0.994
	2	36	14.13	4.85	6.71	23.75	ptp M2 *vs.* TL	28.24000	1.00140	0.968	0.984
Supracleithrum	1	35	31.09	11.75	15.99	57.79	scl M1 *vs.* TL	14.71700	0.96450	0.989	0.995
	2	35	2.52	1.04	1.29	5.01	scl M2 *vs.* TL	177.00000	0.89950	0.964	0.982
Cleithrum	1	35	70.36	28.67	35.02	139.09	cl M1 *vs.* TL	8.42960	0.91150	0.996	0.998
	2	35	34.80	14.07	16.82	68.10	cl M2 *vs.* TL	15.79000	0.91510	0.988	0.994
	3	35	9.12	3.04	5.14	17.04	cl M3 *vs.* TL	37.12200	1.07600	0.892	0.944
Otolith sagitta	1	30	11.53	2.80	7.26	17.53	oto M1 *vs.* TL	12.52300	1.41320	0.963	0.981
	2	30	6.59	1.87	3.85	11.08	oto M2 *vs.* TL	37.20100	1.25850	0.975	0.987

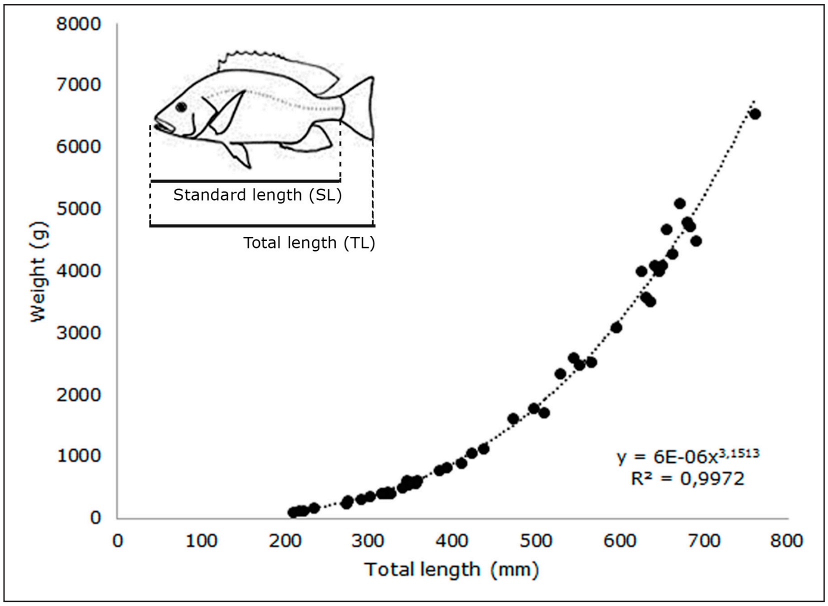

FIGURE 3 | Total length (TL) to weight relationship of the modern sample of *Lutjanus argentiventris*.

The tests made using other species of the same genera (Fig. 4) showed that the model could be used, at least in some instances, at genus level without much distortion. This is an important issue when dealing with *Lutjanus* species from other geographic areas. With regards the GRP profiles, the similar M2 values of the vertebrae of the posterior zone (Fig. 5) allowed us to use their measurement without knowing their exact rank in the rachis, which is often difficult to determine with isolated caudal vertebrae.

The otoliths on both sides can be used to estimate the size of the fish (Tab. 3).

DISCUSSION

The relationships between bone measurements and body-length were robust (Tab. 2), which makes us confident that they can be used with archaeological samples. Also, it is interesting to point out that the model also works with small fish, such as the 109 mm TL Panamanian specimen (Fig. 4). Such applications have already been carried out and have shown their interest. This is notably the case of recent studies in the fresh waters of South America (Peña-León, 2011, 2013; Prestes-Carneiro *et al*., 2019) or in the marine waters of the Persian Gulf (Yeomans, 2015; Lidour *et al*., 2018).

However, this kind of study is not frequent in Latin American archaeological literature of despite its great informative potential. The study of the body length of the archaeological *L. argentiventris* could provide information on where the specimens were captured, depending on their size, and on ancient fishing techniques. The early life stages of *L. argentiventris* are found in mangroves, estuaries or shallow bays, which provide them with food and protection from large predators; adults then move to the outer rocky reefs where they continue to grow (Rojas *et al*., 2004). With this in mind, small-sized archaeological fish are expected to have been captured in mangroves, or at least close inshore, while larger fish came from deeper waters. The proportion of

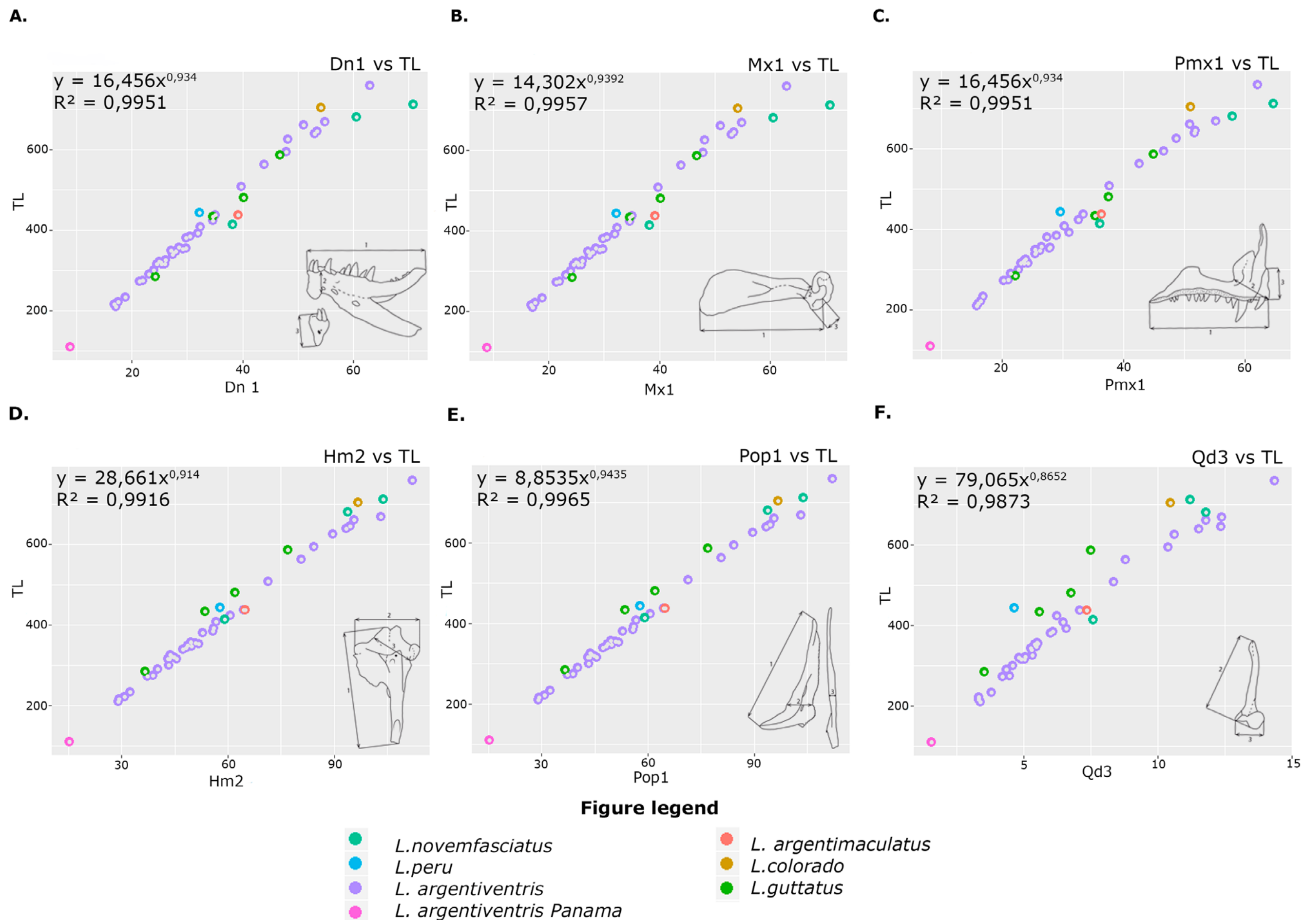

FIGURE 4 | Examples of *Lutjanus argentiventris* graphs modelling the regression formulae. **A.** Dentary (Dn1); **B.** Maxilla (M1); **C.** Premaxilla (Pmx1); **D.** Hyomandibula (Hm2); **E.** Preopercle (Pop1) and **F.** Quadrate (Qd3).

TABLE 3 | *Lutjanus argentiventris* otholith measurements.

Measurement	Side	n	Mean	t	*p*
Length	**right**	30	11.36	-0.0352	0.9721
	left	30	11.36		
Height	**right**	30	6.48	-0.4224	0.6758
	left	30	6.50		
Weight	**right**	30	0.16	2.17E-15	1
	left	30	0.16		

juveniles to adults can also provide information about fishing grounds and/or the health of nurseries and, beyond that, mangroves. However, these inferences should be accepted with caution because different populations of the same species may present different life history characteristics (*e.g.* Rojas *et al.*, 2004, Lucano-Ramírez *et al.*, 2014), and direct interpolation with the past could be risky. Ancient size data obtained from

TABLE 4 | *Lutjanus argentiventris* total length to weight equation parameters from Mexico, Panama and Colombia (*data in cm were transformed into mm).

Reference	Country	a	b
García-Contreras *et al.* (2009)*	Mexico	0.0000126	3.03
Piñón *et al.* (2009)*	Mexico	0.0000087	3.10
Bonilla-Gómez *et al.* (2014)*	Panama	0.0000103	3.07
Rojas *et al.* (2004)	Colombia	0.0000063	3.12
This study	Ecuador	0.0000060	3.15

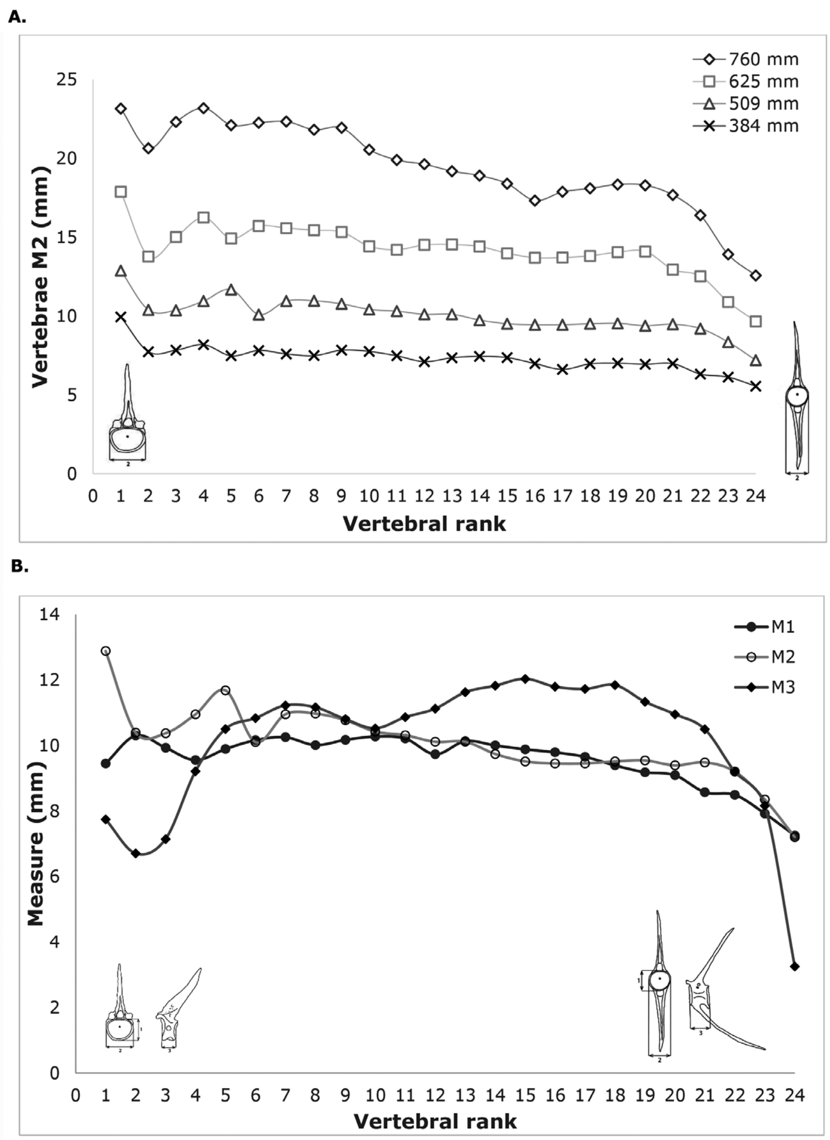

FIGURE 5 | Global Rachidian Profiles of *Lutjanus argentiventris*. **A.** Measurement 2 of four *Lutjanus argentiventris* individuals (TL = 384 mm; TL = 509 mm; TL = 625 mm; TL = 760 mm). **B.** Measurements 1, 2 and 3 of one *Lutjanus argentiventris* individual (TL = 509 mm).

archaeological material could be helpful in modern ecological studies and fisheries management, given that such information could provide insight into: (1) the long-term effects of human activities on fisheries and aquatic ecosystems; (2) the acceleration and geographical extension of these effects over time; (3) the distribution and ecology of past fish populations (Erlandson, Rick, 2010).

The allometric model presented here can be used to predict the size and weight, not only of *L. argentiventris*, but also of its congeners, using isolated bones found in archaeological and paleontological contexts or the stomach contents of piscivorous species. This model could be useful not only for archaeologists but also for biologists working in historical ecology.

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AUTHOR CONTRIBUTION

María Fernanda Martínez-Polanco: Conceptualization, Data curation, Formal analysis & Writing-original draft.

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