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Short Communication

Size and body weight estimation of "gould octopus" *Octopus mimus* A. Gould, 1852 (Cephalopoda: Octopoda) from beak measurements in northern Peru

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ABSTRACT. *Octopus mimus* is an octopod of interest to benthic fisheries in Peru and an important species in food webs. Its beaks or jaws can be found in the stomach contents of various species, making them a useful tool for species identification, as well as for estimating age and biomass. This study aimed to establish regression formulas between beak measurements and mantle length (ML) and body weight (W) of *O. mimus* specimens caught in the adjacent waters of the Lobos de Afuera Islands, Peru. Two hundred fifty beaks were analyzed. Our results showed that the most useful beak measurements for estimating the ML were upper hood length (UHL) and the length of the baseline of the lower beak (LBL). These measures fit logarithmic and exponential equations, respectively. For W, the best measurements were upper crest length (UCL) and LBL, both of which fit exponential equations. This study could be useful in analyzing the diet and trophic ecology of its predator species. It is the first study to develop a regression formula from *O. mimus* beak measurements to estimate ML and W.

Keywords: *Octopus mimus*; regression formulas; mantle length; trophic ecology; stomach contents; octopod

Octopus mimus A. Gould, 1852, is an incirrate octopus of interest to benthic fisheries as it is a marine resource commonly consumed by humans (Cabrera 2014, Sauer et al. 2021). This species inhabits rocky intertidal reefs from 0 to 30 m in depth (Jereb et al. 2014) in the southeastern Pacific, specifically on the southern coast of Ecuador, Peru, and northern Chile (2-27°S) (Ibáñez et al. 2024). It is a carnivorous organism and is considered opportunistic as it presents a wide variety of prey, among which crustaceans and mollusks are its main prey, followed by other invertebrates and fish (Cortez et al. 1995a, Cardoso et al. 2004, Cisneros 2019).

Octopods are part of the diet of many marine species, as the presence of both whole specimens and their beaks or jaws has been found in the stomach contents of elasmobranchs (González-Pestana et al. 2021, Molina-Salgado et al. 2021), marine mammals (Blanco et al. 2001, Evans & Hindell 2004, Sielfeld et al. 2018), sea turtles (Jiménez et al. 2017), seabirds (Herling et al. 2005, Nishizawa et al. 2018, Tobar et al. 2019), and cephalopods (Ibáñez et al. 2021). Cephalopod beaks are found in the stomachs of these predators due to their hardness and resistance to digestive enzymes, which prevent them from degrading (Clarke

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1962). Cephalopod beaks are unique by species, which makes them a useful body structure for their identification at the species level (Clarke 1986, Gröger et al. 2000), age quantification (Araya et al. 1997, Raya & Hernández-González 1998, Batista 2011), and are used to develop regression formulas that help to estimate the size or body weight of specimens (Wolff 1984, Lalas 2009, Açik & Salman 2010, Xavier & Cherel 2021). Species-level information, as well as the size or weight of cephalopod specimens, is used to gain insights into prey-predator interactions (Lu & Ickeringill 2002). This information can also be used to determine the level of prey hierarchy in predator stomach contents through the prey-specific relative importance index (PSIRI) (Brown et al. 2012).

There have been several studies that use beak measurements to estimate weight and size in other species of the genus *Octopus*, such as *O. vulgaris*, *O. variabilis*, and *O. superciliosus*, among others (Clarke 1962, Lu & Ickeringill 2002, Xue et al. 2013). As for *O. mimus*, its age and growth have been estimated in Chile between Arica (18°28'S) and Tarapaca (21°38'S), where the beaks of specimens were used to establish relationships with their growth (Araya et al. 1997). However, the present study represents the first to estimate the relationship between body size and body weight based on *O. mimus* beak measurements. Therefore, this study aims to establish regression formulas between beak measurements with mantle length (ML) and body weight (W) of *O. mimus* specimens from the Lobos de Afuera Islands, located on the northern coast of Peru.

Specimens of *O. mimus* were collected bimonthly for one year, from November 2020 to November 2021, at Lobos de Afuera Islands, Lambayeque, Peru (06°56′S, 80°42′W) (Fig. 1a). All specimens were acquired through direct purchase from local fishers (divers). A total of 300 specimens were sexed, weighed fresh (g), and the ML (mm) was measured. Subsequently, the beak extraction procedure, as described by Clarke (1986), was followed, and the beaks were preserved in 70% alcohol for analysis at the Pro Delphinus facility. In the laboratory, beaks were cleaned, and tissue debris was removed. Upper and lower beaks were measured using a digital vernier caliper. The measurements considered were: upper wing length (UWL), upper hood length (UHL), upper crest length (UCL), upper rostral length (URL), and the amplitude of the lateral wall (Lwa) for the upper beak, and lower wing length (LWL), lower hood length (LHL), lower crest length (LCL), lower rostral length (LRL), and baseline length (LBL) for the lower beak (Açik & Salman 2010) (Fig. 1b-c).

The normal statistical distribution of ML, W, and beak measurements was evaluated using the Shapiro-Wilk test. Additionally, to evaluate statistical differences between sexes for each measurement, the non-parametric Wilcoxon test was applied, except for LBL, where Student's *t*-test was utilized. The statistical difference in the relationship between ML and W by sex was also assessed using the analysis of covariance (ANCOVA) (Xue et al. 2013). The relationships among beak measurements were also examined. Due to the non-normal distribution, Spearman's rank correlation coefficient was used (Pearson's coefficient for LBL) to determine if all beak measurements had positive or negative correlations. Finally, linear, power, exponential, and logarithmic models were used to analyze the relationship between beak measurements and the ML and W. In these models, y represents ML or W, x denotes the beak measurements, and *a* and *b* are the adjusted parameters. To determine the best model for each relationship, the Akaike information criterion (AIC) and root mean square error (RMSE) were calculated. The model with the smallest AIC and RMSE indicated the best fit. Among the selected models, those with the highest coefficient of determination (R^2) were considered the most suitable for estimating ML and W. Statistical analyses were conducted using RStudio 4.1.2 software (R Core Team 2022). In the case of the model fit, the algorithm "port" was used in the function "nls".

In this study, only specimens with beaks in good condition (n = 250) were included; those with worn or damaged beaks were excluded. Female specimens (n = 99) ranged from 55-200 mm (ML) and weighed between 100.14-2,161.91 g (W), with a mean of 112.58 mm and 771.71 g, respectively. On the other hand, males (n = 151) ranged in size from 64-181 mm (ML) and weighed between 132.43-1,997.75 g (W), with a mean of 106.75 mm and 645.96 g, respectively.

The Wilcoxon test for mean comparison ($P > 0.05$) indicated that there were no significant differences between beak measurements by sex. Four statistical models were also applied to analyze the relationship between ML and W in females and males, with the potential model yielding the best fit to the data, having an RMSE of 10.91. The ANCOVA analysis showed that ML had a significant effect on W ($F = 729.59$; $P < 0.05$), but sex did not ($F = 1.79$; $P > 0.05$); similarly, W significantly influenced ML ($F = 724.43$; $P < 0.05$), but sex did not ($F = 0.03$; $P > 0.05$). For these reasons, the subsequent analyses were performed combining both sexes. The Shapiro-Wilk test showed that the combined ML and W data did not follow a normal distribution.

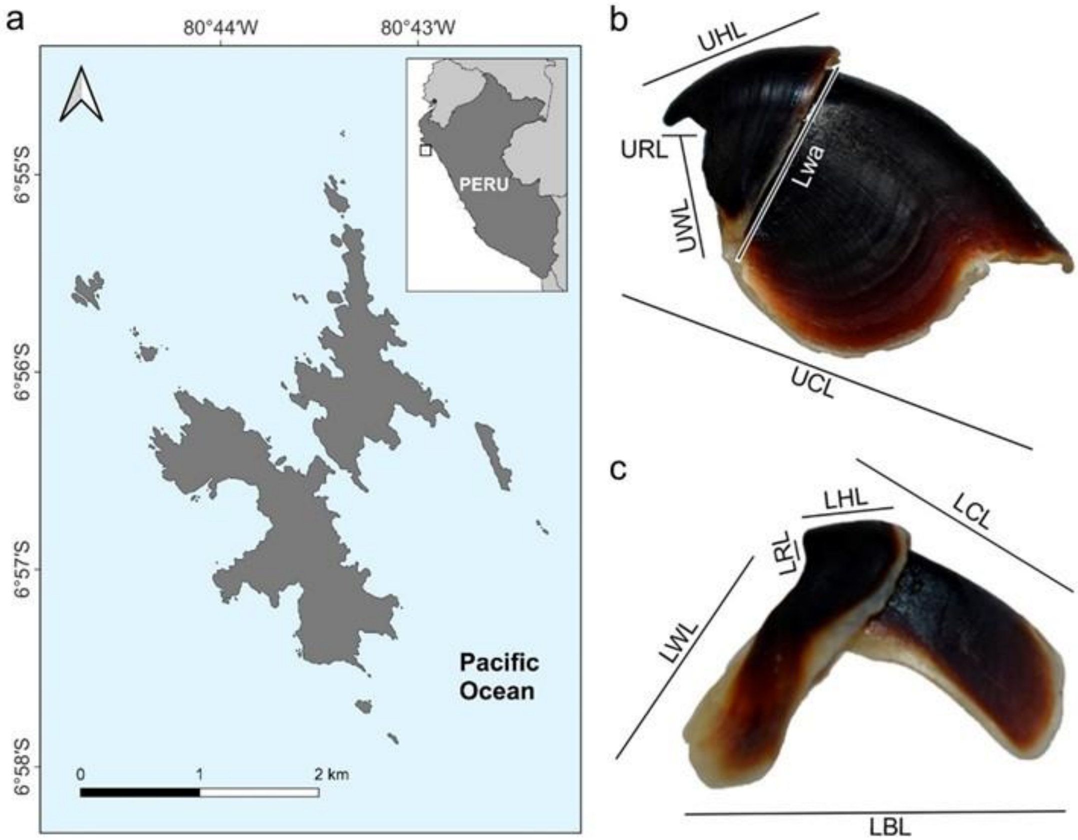

Figure 1. a) Location map of Lobos de Afuera Islands, Lambayeque, Peru. Photograph of the b) upper and c) lower beak of *O. mimus*. UHL: upper hood length, UCL: upper crest length, UWL: upper wing length, URL: upper rostral length, Lwa: amplitude of the lateral wall, LHL: lower hood length, LCL: lower crest length, LWL: lower wing length, LRL: lower rostral length, LBL: lower baseline length.

According to the Shapiro-Wilk test, beak measurements follow a non-normal distribution, except LBL ($P > 0.05$). Additionally, they were compared with each other, yielding the finding that they all exhibited significant linear relationships. All these comparisons presented strong positive Spearman's correlations. The relationships that presented the highest correlation were UCL with LWL, LCL, and LBL, presenting a Spearman's coefficient of 0.97 ($P < 0.05$). Similarly, the other relationships presented high coefficients, ranging from 0.76 to 0.95, all of which were statistically significant ($P < 0.05$).

Analysis of the relationship between beak measurements and ML indicates that most of the relationships (LHL, LCL, LRL, UWL, UHL, UCL, URL, Lwa) fit better to a logarithmic model, except for LWL and LBL, which fit linear and exponential models, respectively. On the other hand, the relationship between the measurements of the beak and W indicates that most of the relationships (LWL, LCL, LBL, UHL, UCL, URL, and Lwa) fit better to an exponential model, except for the LHL, which fits a linear model, and the LRL and UWL fit a power model (Table 1, Fig. 2).

In the present study, it was observed that the specimens of *O. mimus* analyzed did not present significant differences in the measurements of ML and W between sexes, indicating that it is more appropriate to analyze the combined data. The use of combined data for analyzing predator stomach contents may be appropriate, as morphological changes during digestion can preclude sex differentiation (Xavier et al. 2007).

The AIC was used to determine which model fits the data better, with logarithmic and exponential models having the best fit for beak measurements. Among the beak measurements, the UHL ($R^2 = 0.33$) and LBL ($R^2 = 0.34$) were the most effective in estimating the ML. At the same time, the UCL ($R^2 = 0.50$) and LBL ($R^2 =$

Table 1. Best fit models for relationships between beak measurements with mantle length (ML in millimeters) and body weight (W in grams) of *O. mimus*. ML and W: dependent variable (y), beak measurements: independent variable (x), *a* and *b*: model parameters, R^2: determination coefficient, AIC: Akaike information criterion, RMSE: root mean square error, UHL: upper hood length, UCL: upper crest length, UWL: upper wing length, URL: upper rostral length, Lwa: amplitude of the lateral wall, LHL: lower hood length, LCL: lower crest length, LWL: lower wing length, LRL: lower rostral length, LBL: lower baseline length.

	Beak measurement	Model	Equation	R^2	*P*-value	AIC	RMSE
ML	LWL	Linear	ML = 50.38 + 5.93LWL	0.28	<0.05	2202.75	19.58
	LHL	Logarithm	ML = 63.93ln(LHL) + 14.13	0.30	>0.05	2197.71	19.38
	LCL	Logarithm	ML = 69.24ln(LCL)-54.39	0.32	<0.05	2188.60	19.03
	LRL	Logarithm	ML = 55.31ln(LRL) + 68.84	0.27	<0.05	2205.97	19.71
	LBL	Exponential	$ML = 55.66^{0.05LBL}$	0.34	<0.05	2182.68	18.81
	UWL	Logarithm	ML = 52.04ln(UWL) + 30.30	0.26	<0.05	2209.18	19.83
	UHL	Logarithm	ML = 77.02ln(UHL) - 44.12	0.33	<0.05	2183.25	18.83
	UCL	Logarithm	ML = 68.03ln(UCL) - 85.75	0.33	<0.05	2185.83	18.93
	URL	Logarithm	ML = 48.93ln(URL) + 71.55	0.23	<0.05	2221.09	20.31
	Lwa	Logarithm	ML = 57.87ln(Lwa) - 9.52	0.28	>0.05	2203.32	19.60
W	LWL	Exponential	$W = 110^{0.18LWL}$	0.44	<0.05	3582.03	308.93
	LHL	Linear	W = -544.06 + 275.46LHL	0.37	<0.05	3613.32	328.88
	LCL	Exponential	$W = 101.76^{0.17LCL}$	0.46	<0.05	3571.02	302.21
	LRL	Power	$W = 211.66LRL^{1.56}$	0.36	<0.05	3614.85	329.89
	LBL	Exponential	$W = 70.04^{0.15LBL}$	0.50	<0.05	3551.34	290.54
	UWL	Power	$W = 50.95UWL^{1.68}$	0.42	<0.05	3590.44	314.17
	UHL	Exponential	$W = 91.54^{0.27UHL}$	0.43	<0.05	3587.50	312.33
	UCL	Exponential	$W = 89.96^{0.11UCL}$	0.50	<0.05	3553.53	291.82
	URL	Exponential	$W = 160^{0.64URL}$	0.35	<0.05	3617.38	331.57
	Lwa	Exponential	$W = 114.98^{0.22Lwa}$	0.45	<0.05	3578.53	306.77

0.50) were the optimal measurements for estimating the W. Similar results have been observed in other species of the genus *Octopus* from southern Australia, where the UHL measurement was found to be the most effective for size estimation (Lu & Ickeringill 2002). A similar finding was observed in *O. variabilis* in the northwest Pacific Ocean, where UHL was the optimal measure for estimating size. As for W, the UCL and LCL measures presented better coefficients of determination (Xue et al. 2013). In northern Chile, between Arica and Tarapacá, regression formulas were obtained between LHL and the ML and W of *O. mimus*. However, these calculations were performed to determine whether there was any relationship between growth and the beak measure in any morphometric variable (Araya et al. 1997).

Hard structures, such as cephalopod beaks, are frequently used in stomach content analysis of higher trophic level predators, as they have a low digestion rate and are useful for species identification and estimation of the total mass of ingested prey (Vega 2011, Córdova et al. 2018, Gonzalez-Pestana et al. 2021). Measurements of the length of the cephalopod beak have been used to estimate the total mass of specimens in different studies, such as the stomach contents of scombrids, billfishes, marine mammals, and elasmobranchs, among others (Tollit et al. 1997, Potier et al. 2011, Córdova et al. 2018, Molina et al. 2021). On the other hand, measures of the beak that are less prone to damage in the stomach contents of predators include LHL and UCL (Kashiwada et al. 1979, Lu & Ickeringill 2002, Xue et al. 2013). Even so, it is recommended that beaks should be treated with extreme care at the time of extraction or when handling them during stomach content analysis, as inclusion of broken or eroded beaks could yield erroneous estimates (Potier et al. 2011, Xue et al. 2013).

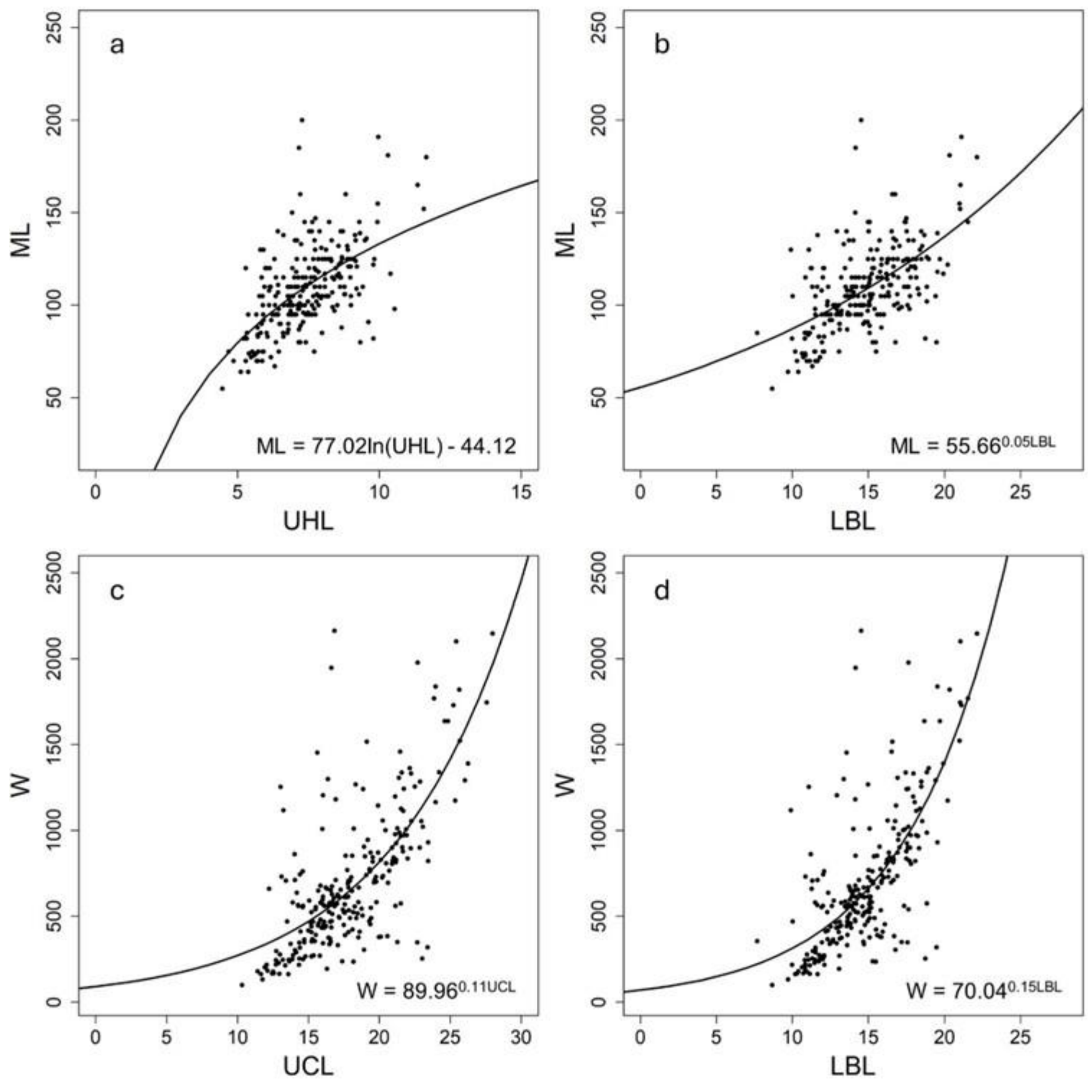

Figure 2. Relationship between mantle length (ML in millimeters) with a) upper hood length (UHL) and b) lower baseline length (LBL), and body weight (W in grams) with c) upper crest length (UCL) and d) LBL.

Morphometric variations of the beak can be influenced by factors such as growth, sex, geographic location, and environmental conditions (Boyle & Boletzky 1996, Açik & Salman 2010). Some species of octopods, such as *O. vulgaris*, have a digestive gland related to beak growth such that during rest periods, more resources are available for beak growth, while in highly active periods, growth rates decline since there is a greater bodily demand for energy (Kayes 1973, Castanhari & Tomás 2012). One must consider, therefore, that in reproductive periods, females direct somatic resources to ensure an adequate level of propagule production and embryo development (Cortez et al. 1995b). Thus, although sampling occurred over a one-year period, the relationships observed in the present study should be viewed with caution, considering possible factors that may affect the species (e.g. breeding season, oceanographic conditions, and environmental factors). The equations obtained in this study can inform future biological and ecological research on the contribution of *O. mimus* in the diets of other marine species. However, we recommend conducting similar studies for *O. mimus* in other geographic regions of the species' distribution (e.g. the central and southern coasts of Peru and regions of Chile) to ascertain whether similar patterns are found among different populations of *O. mimus*.

The UHL and LBL measures were the best for ML estimation, while for W estimation, UCL and LBL were the best measures of *O. mimus*. This study can be used to determine the size and body weight of *O. mimus* in the diet and trophic ecology of its predatory species, as it is the first to develop a regression formula for estimating ML and W of *O. mimus* from beak measurements.

Author's contribution credits

R. Torrejón-Zegarra: conceptualization, methodology, formal analysis, investigation, writing-original draft, writing-review and editing; V. Arrese-Dávila: conceptualization, methodology, investigation, writing-original draft, writing-review and editing; J. de la Cruz: validation and resources; P. Ramírez: validation and resources; J. Alfaro-Shigueto: validation, resources, writing-review and editing, and funding acquisition; J.C. Mangel: validation, resources, writing-review, editing, and funding acquisition; A. Gonzalez-Pestana: validation, formal analysis, writing-review and editing; D. Espinoza-Morriberón: formal analysis, writing-review and editing; J. Castro-Gálvez: validation and resources; D. Correa: validation and resources.

Conflict of interest

The authors declare they have no conflict of interest.

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