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Multidimensional indices for the sea cucumber *Holothuria grisea* biometry

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Abstract
Holothuria grisea is the most abundant sea cucumber on the Brazilian coast and plays an important ecological role in marine ecosystems. Several reports have documented the seizure of individuals intended for illegal export, along with an apparent decline in natural populations. The species' water retention capacity and body viscoelasticity cause significant variation in length and width when handled, making it necessary to develop reliable multidimensional biometric indices for conservation and aquaculture purposes. In this study, two-dimensional indices, particularly SLW and estimated length, provided the most accurate predictors of body weight.

Keywords: Sea cucumber, morphometry, holothurian, weight-length relations

Resumo - Índices multidimensionais para biometria do pepino-do-mar *Holothuria grisea*
Holothuria grisea é o pepino-do-mar mais abundante na costa brasileira e desempenha um papel ecológico importante no ecossistema marinho. Tem havido vários relatos de apreensões de animais ilegalmente destinados à exportação e um aparente declínio nas populações naturais. As características de retenção de água do pepino-do-mar e a viscoelasticidade do seu corpo, que promove alterações significativas no seu comprimento e largura quando manipulado, tornam necessário estabelecer índices multidimensionais confiáveis para a biometria, para fins de conservação e aquicultura. No presente estudo, estes índices bidimensionais, o SLW e o comprimento estimado, forneceram os preditores mais precisos do peso corporal.

Palavras-chave: Pepino do mar, morfometria, holothurias, relações pelo e comprimento

Resumen - Índices multidimensionales para la biometría del pepino de mar *Holothuria grisea*
Holothuria grisea es el pepino de mar más abundante en la costa brasileña y desempeña un papel ecológico importante en el ecosistema marino. Se han registrado varios casos de incautación de ejemplares destinados ilegalmente a la exportación y se observa un aparente declive en las poblaciones naturales. Las características de retención de água del pepino de mar y la viscoelasticidad de su cuerpo, que provoca cambios significativos en su longitud y anchura cuando se manipula, hacen necesario establecer índices multidimensionales fiables para la biometría, con fines de conservación y acuicultura. En el presente estudio, estos índices bidimensionales, el SLW y el longitud estimado, proporcionaron los predictores más precisos del peso corporal.

Palabras clave: Pepino de mar, morfometría, holoturio, relaciones peso-longitud

Introduction

Holothuria grisea sea cucumbers play a fundamental ecological role in benthic ecosystems, acting mainly as detritivores, ingesting surface sediment and utilizing organic matter, contributing significantly to the process of nutrient recycling on the seabed (Brusca, 2019).

The species *H. grisea* is native to the Brazilian coast and can be found in abundance from the Northeast region (2ºS 41ºW) to the south of Santa Catarina (29ºS 49ºW), in intertidal zones, at the base of rocks, and in contact with bottom sand (Mendes, Marenzi & Domenico, 2006). Rupp, Marenzi, Souza, & Martins (2023) reported that the species can occur in densities of up to 8 individuals/m² on the coast of Santa Catarina.

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The species has a cylindrical body with distinct, ventrally flattened warts; maximum length detected is 225 mm. Body wall coloration varies from gray to brown; yellow tubular feet cover the body (figure 1), more abundant in the ventral region.

Figure 1. Specimens of *Holothuria grisea* from the experimental stock of the Marine Shrimp Laboratory / UFSC

In Brazil, although there are no official records of domestic consumption of the sea cucumber *H. grisea*, there are frequent reports of unregulated and unsustainable fishing of this species for illegal export, especially in the states of Rio de Janeiro, Santa Catarina, and Ceará. Ponte, Coe, Lobo Farias, Mercier & Hamel (2017) reported an annual catch of over 12 tons of fresh gutted animals in just one municipality in Ceará, in northeastern Brazil. These same authors inferred a population reduction of 98.7% in just three years in the region.

The exploitation and overfishing of low trophic level invertebrates have been occurring and growing at a rate that regulation, enforcement, and management strategies are unable to keep up with (Anderson, Flemming, Watson & Lotze, 2011). A cycle of rapid expansion in sea cucumber harvesting, followed by a rapid decline in populations, has been observed in several countries around the world (Uthicke, Schaffelke, & Byrne, 2009). The decimation of stocks has forced recent moratoriums in more than 15 countries (Purcell, 2010). However, according to Conand (2006), moratoriums end up in most situations encouraging illegal capture and trade.

As traditional fishing spots and markets in Southeast Asia deplete their local stocks, fishing pressure is shifting to new regions and previously underutilized species, including populations in the South Atlantic (Fantinelli et al., 2025).

Although *H. grisea* is not listed as threatened on the IUCN Red List, there is a significant gap in the conservation status of sea cucumber species. The data are based on information from 2010 (Fantinelli et al., 2025). And it certainly does not consider the actual growing demand and the increase in illegal fishing and exports of *H.grisea* from Brazil.

Nearly 40% of the animals confiscated in world recent operations against illegal commerce were juveniles, indicating that hunting pressure is hindering the recruitment and renewal of natural populations (Bondaroff & Morrow, 2024). Furthermore, the IUCN Red List indicates that 65% of the assessed Holothuroidea species are classified as Data Deficient (DD), reflecting insufficient knowledge about their populations and conservation needs (IUCN, 2025).

Most tropical species tend to occur in shallow waters, in the supralittoral zone, within the range of free diving, or in the case of *H. grisea* and other tropical species, on coastal cliffs and rock outcrops that allow manual collection without the fisherman having to enter the water (Kinch, Purcell, Uthicke & Friedman 2008; Rupp, Marenzi, Souza, & Martins, 2023). Sea cucumbers move very slowly and have almost no ability to escape (Conand, 1991).

Population studies for fishing and ecological purposes rely fundamentally on biometric science and morphometry to characterize the relative sizes of animals in each population, their temporal evolution, and the establishment of capture strategies and quotas, generally based on the weight of the animals caught (Leopold et al., 2013; Purcell, 2010). It is often impractical for fishermen/collectors or even occasional inspectors to take weight measurements in the field. Consequently, length-weight relationships are an important tool in planning the management of fishery resources, especially marine resources (Prescott, Zhou & Prasetyo, 2015).

Achieving accuracy and reliability in sea cucumber biometry has been a challenge for researchers, both for length and width measurements, since sea cucumbers have high viscoelasticity, malleable collagenous tissues and tend to contract their bodies when handled for measurement (Hammond & Purcell, 2024; Djenidi, Purcell, Thornton, Gossuin & Gilbert, 2024), significantly altering length and width measurements (González-Wangüemert, Valente, Henriques, Domínguez-Godin & Serrão, 2016).

By modulating extracellular calcium (Ca^{2+}) and potassium (K^{+}) levels, the sea cucumber can switch between states of extreme flexibility and structural rigidity without the metabolic cost associated with continuous muscle contraction (Mo et al., 2016). This mechanism is essential for maintaining posture in rock crevices and for defense against predators, but it introduces significant errors in field measurements of length and width.

In addition, to obtain live weight, animals may retain different volumes of water and sediment at the time of weighing (Skewes et al., 2004). Djenidi, Purcell, Thornton, Gossuin & Gilbert (2024) obtained an average change of 31.93% the animal's body weight after 10 minutes out of water and indicate that time spent out of the water significantly affects the animal's weight.

However, despite this possibility of weight being biased by the amount of water retained, several authors point out that the estimation of body length is subject to a greater error than weight, since it is very difficult to obtain total relaxation of the sea cucumber's body (Conand, 1981; Tuwo & Conand, 1992; Kazanidis, Chryssanthi, Lolas & Neofitou, 2010).

Two-dimensional indices and morphometric relationships can help establish more reliable body measurements and relationships and reduce reading errors or differences in measurements between individuals of similar sizes in practice (Prescott, Zhou & Prasetyo, 2015; Poot-Salazar, Hernández-Flores & Ardisson - Salazar, 2014; Rupp, Marenzi, Souza & Schroeder, 2024).

Therefore, the objective of this study was to establish biometric methodologies and protocols for the species.

Materials and Methods

Collection of experimental specimens

Conducted in two sampling periods, the collections were carried out at the geographical coordinates 26°47.3882'S 48°36.8194'W, located in Itapocoroy bay in the municipality of Penha, Santa Catarina, at peak low tide times.

The animals were attached to exposed marine rocks or the ocean floor, momentarily exposed at that moment of the tide, out of the water, or at a depth of up to 0.80 m.

The animals were collected by simple random sampling, i.e., there was no prior selection by size or any other specific criteria. Thus, all animals in the population had the same probability of being selected to compose the population samples for each year.

Both collections took place in April/May, in the southern hemisphere's autumn, outside the species' main reproductive period and at a time of relative food abundance.

The first collection took place in March 2024, with the manual capture of 48 animals ranging in length from 6.5 cm to 14.5 cm and weighing from 21.79 g to 85.92 g. The animals were transported immersed in seawater from the site in 60-liter Styrofoam boxes, with an estimated transport time of 3 hours.

The second collection took place in May 2025, with manual capture of 260 animals ranging in length from 4.0 cm to 19.50 cm and weighing from 8.26 g to 108.55 g. The animals were transported in a 400-liter transport box with forced aeration and a transport time of 3 hours.

Biometry

In both collections, the sea cucumbers were previously removed from the water for approximately 5 minutes to expel excess body water and relax the body after capture handling, aiming to reduce potential measurement errors according to the methodology proposed by Skewes et al. (2004).

The animals were initially measured for length using a ruler with 1 mm precision, width was measured using a caliper with 0.1 mm precision, and they were then weighed on electronic scales with 0.01 g precision

Subsequently, 14 animals were slaughtered to determine the percentage of water and coelomic fluid relative to the total body weight recorded during biometric measurements. The muscle mass and viscera of these animals were weighed separately, and body proportions were calculated

Analytical procedures

All data were processed separately by year of collection.

After obtaining the length, width, and weight measurements of all animals, the mean, standard deviation, and coefficient of variation were calculated. Sturges' formula (Sturges, 1926) was used to determine the number of classes in the frequency distribution.

Two two-dimensional indices were obtained, the basal area and the square root of the length x width (SLW) product, as proposed by Yamana & Hamano (2006) and later described and used by Hammond & Purcell (2024):

Basal area: A= Π x L/2 x W/2

SLW=$\sqrt{(L\ x\ W)}$

L is the observed length

W is the observed width

The regression between the observed length and SLW was calculated to establish the estimated length (Le), weighted from the two-dimensional SLW measurement, where the dependent variable (y) was the observed length and the independent variable (x) was the SLW.

Linear regressions were calculated between the observed weight and observed length, observed weight, and estimated length, observed weight and basal area, and observed weight and SLW.

Pearson's correlation between the observed length and the SLW index was also established.

Mathematical and statistical analyses were performed using the Python programming language (Python software foundation, 2024).

An allometric extrapolation was performed for the animals from the 2025 according to the formula

$Y= aW^b$

W – weight, a and b coefficients

Results

The averages of the observed length, observed width, and weight of the 2024 and 2025 collections are presented in Table 1, while the distribution of length classes is show in Table 2.

The lowest coefficients of variation were obtained for SLW and estimated length, indicating that these indices are best suited for morphometric characterization of populations, while among the two-dimensional indices, basal area had the highest coefficient of variation, even higher than that obtained for observed length (Tables 1 and 2).

Table 1. Means ± standard deviation of the measurements observed by biometry in the 2024 and 2025 collections.

	2024	2025
N	48	260
Weight (g)	48,80 ± 15,84	47,28 ± 22,62
Length (cm)	10,40 ± 1,73	11,15 ± 2,68
Width (cm)	2,80 ± 0,75	2,38 ± 0,51

Table 2. Means, standard deviation, coefficients of variation, and regression coefficients.

	MÉDIA ± SD		CV	
	2024	2025	2024	2025
Basal area	23,50 ± 5,85	21,42 ± 8,37	24,90	39,07
SLW	5,40 ± 0,69	5,12 ± 1,03	12,74	20,16
Length	10,40 ± 1,73	11,15 ± 2,68	16,55	24,05
L_e	10,40 ± 1,33	11,15 ± 2,41	12,72	21,65
Weight	48,80 ± 15,84	47,28 ± 22,62	32,47	47,84

Regarding the observed measurements, the coefficient of variation for weight was considerably higher than that for length, suggesting the possibility that the species studied has greater water retention compared to body contractility, or even an ineffectiveness of the method in ejecting body water before weighing (Table 2).

The regressions calculated between the observed length and the estimated indices can be seen at Table 3. Figures 2 and 3 show the graphical representation of the regressions, with their r^2 and the curve formula.

Table 3: Regression coefficients between observed body length, estimated length, and two-dimensional indices Basal area, SLW, L_e.

	r^2	
	2024	2025
Basal area	0,67	0,74
SLW	0,67	0,73
Length	0,48	0,60
Le	0,67	0,73

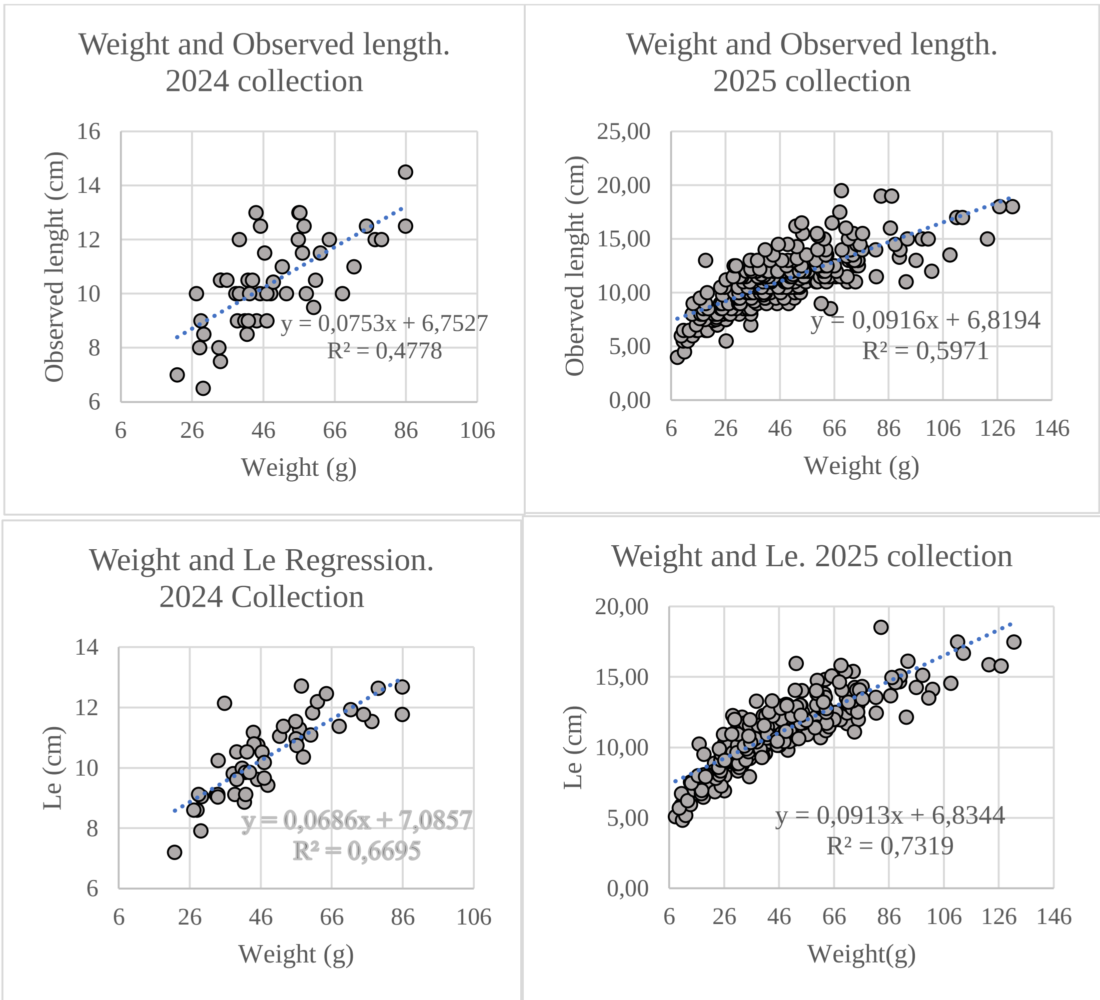

Figure 2. Regressions between observed weight and length and estimated weight at length (Le).

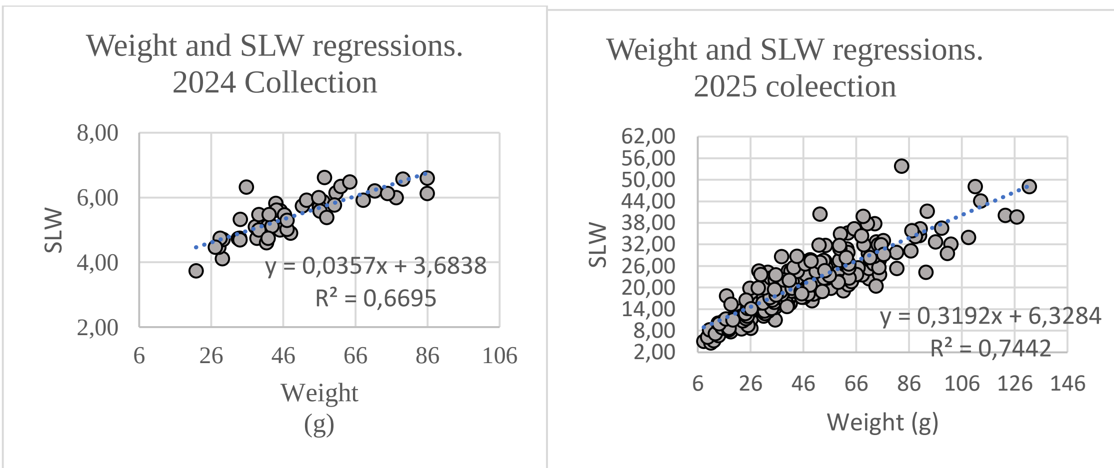

Figure 3. SLW and weight regressions.

The Pearson correlation between SLW and Le was calculated, and the values obtained of 0.9997 and 0.9999 (2024 and 2025, respectively) demonstrated a strong positive correlation between these indices for the H. grisea populations studied.

The observed negative allometry (b<3) suggests that the H.grisea grows in length more rapidly than it gains weight, a characteristic common among holothurians with elongated bodies. This pattern may be an adaptation to maximize feeding surface area or to facilitate burrowing into sandy substrates among rocks (Poot-Salazar, Hernández-Flores, & Ardisson -Salazar, 2014).

The % proportions of body parts obtained after the animals' slaughter are presented in Table 4

Table 4. Bodies components proportion after 5 min out of water

	Muscular tissue	Viscera	Water + coelomic contents
Média (%)	56,29%	10,15%	33,56%

Discussion

Biometric assessments of sea cucumber populations using only collected and/or observed measurements such as weight, length, and width have methodological limitations due to the animals' body contractility and differential water retention in their bodies (Hammond & Purcell, 2024).

The body proportion data and the amount of water and coelomic content was similar to that obtained by Djenidi, Purcell, Thornton, Gossuin & Gilbert (2024) working with *H. lessoni*, 33,56% in our study versus 31,93% in the previous case, although in this case the time out of water was 10 minutes instead of 5 minutes of our work.

The data obtained for *H. grisea* were like those for other holothurians (Rupp, Marenzi, Souza & Schroeder, 2024; Hammond & Purcell, 2024; Mendes, Marenzi & Domenico, 2006; Khodja & Mezali, 2023).

The coefficient of determination of 0.5971 in the 2025 collection (figure 7) for the relationship between length and weight was similar to that obtained by Rupp, Marenzi, Souza & Schroeder (2024) of 0.62, working with N=360 animals in the years 2019-2020. Farias-Dias (2012) obtained a coefficient of determination of 0.54 in the length and weight regression of H. grisea from a population of 620 animals collected in northeastern Brazil.

The coefficient of determination of 0.7442 between SLW and weight calculated in this study (figure 8) was also close to the value obtained by Rupp, Marenzi, Souza & Schroeder (2024).

Purcell et al. (2023) consider that the construction of the SLW index would be an appropriate approach for elongated and highly viscoelastic species of the Holothuriidae family that are also exploited, including *H. grisea*.

Geographic variations between two-dimensional indices have already been observed for other sea cucumber species (Mendes, Marenzi & Domenico, 2006; Hammond & Purcell, 2024), suggesting that morphometric indices and equations should be constructed for each population, as it is not possible or reliable to extrapolate data from one population to the entire species.

Similarly, Hammond & Purcell (2024) have also reported seasonal variations in the indices, mainly due to the temporal and differential availability of food and the physiological reproductive stage of the population at the time of collection.

The coefficient of determination was 0.7319 between Le and weight in this study (figure 8), representing a good fit to explain the joint variation.

Yamana and Hamano (2006) compared Le with the length measurement of sea cucumbers *Apostichopus japonicus* taken under menthol anesthesia, the most reliable method for length measurements, but difficult to implement in the field. They concluded that the errors and residuals between the measurements of anesthetized animals and the calculated Le measurement were small and that Le could be used as a biometric index in the field with accuracy and reliability.

In the present study, the two-dimensional indices of SLW and estimated length (Le) provided the most accurate predictors of body weight and are therefore the indices recommended by the study.

The data generated in this study contribute to the establishment of a morphometric model for studies related to conservation of the species, further confirming the body relationships obtained by Rupp, Marenzi, Souza & Schroeder (2024), with an interval of 4 to 6 years between collections.

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