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24 月龄紫刺参养殖形态性状与体质量的关系

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摘 要：以24月龄紫刺参作为研究对象,采用回归分析的方法,研究紫刺参养殖形态性状与体质量的关系。为获得更精确的形态性状与体质量(TW)的关系,将紫刺参体长(L)、体宽(W)和理论体长Le[由SLW(square root of the length-width, $\sqrt{L\times W}$)转换而来]分别与体质量进行拟合,筛选评价紫刺参形态性状与体质量关系的最佳形态参数和曲线模型。结果显示,紫刺参体长、体宽、SLW和体质量等各性状的变异系数(CV)在31.52%～66.85%波动,体质量的变异系数最大,SLW的变异系数最小。回归分析表明,紫刺参各形态性状与体质量关系的最优拟合模型均为幂函数,且理论体长Le是描述紫刺参形态性状-体质量关系的最优形态指标;紫刺参为负异速生长模式,即形态性状的增长快于体质量的增加。研究结果可为紫刺参的生长规律研究和养殖管理提供科学依据和参考资料。

关键词：紫刺参；形态性状-体质量关系；形态性状；体质量
中图分类号：S 917 **文献标志码**：A

刺参(*Apostichopus japonicus*)属于棘皮动物,是目前国内外重要的高附加值渔业经济物种[1],具有极高的营养与医用价值。刺参体型与形态尤为特殊,为典型的圆柱形,骨骼退化为细小的桌形体,身体柔软,伸缩性很大。紫刺参是刺参中一个独具特殊表观特征的品系,其通体呈紫色,外观鲜艳亮丽,生长速度快,较普通刺参更具市场开发潜力[2]。本研究团队于2007年率先对紫刺参开展了一系列高强度选育及其生长[2]、发育[3]、营养等相关基础生物学研究工作,其他方面,目前仅见零星关于紫刺参体色形成特征及机制[4]的研究,而生长性状方面的研究鲜见报道。

因刺参独特的生物学特性,体长、体质量等关键生长性状难以精准定量,常用的刺参体长表示方法有自然体长、舒展体长[5]或收缩体长[6]及复合形态指标[7]等,体质量的表示方法有湿重、肉皮质量和水中体质量[8]等,目前尚未有统一的体长和体质量测定标准。有研究表明,海参形态性状-体质量关系中的参数能够表明不同发育阶段、不同区域生物体生长速率的差别,但世界上大多数海参的重要生物学参数尚不清楚[9-11]。迄今为止,养殖刺参形态性状-体质量关系尚未见报道,有关紫刺参生长规律和生长特性的研究也尚未系统开展。鉴于此,本研究通过不同模型对养殖紫刺参形态性状和体质量进行回归分析,通过建立形态性状-体质量关系的方法间接评估养殖紫刺参群体的生长,旨在探究紫刺参的生长规律和生长特征,并为紫刺参的养殖管理提供科学依据和参考资料。

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1　材料与方法

1.1　数据来源和测量

2020 年 5 月,在山东省海洋科学研究院种质资源研究中心鳌山实验基地室内,采用随机取样的方法,共采集 300 头选育的 24 月龄紫刺参样本,暂养于 8 m^3 养殖玻璃钢槽中。紫刺参养殖用水为砂滤后的自然海水,盐度 32.0 ± 0.6,pH 8.1 ~8.3,溶解氧(DO) 5.8 ~6.5 mg · L^{-1},温度为 2.0 ~30.8 ℃。投喂饲料为商品配合饲料,投喂量为体质量的 3%,投喂时搭配 3 倍的干海泥,通过稀释匀浆发酵后,于每日 15:00 进行投喂,投喂量根据刺参摄食情况在 2% ~4% 范围内调整。日换水 1 次,换水量为养殖水体的 2/3,定期泼洒微生态制剂等生物制剂。

选取紫刺参个体的体长 L(length)、体宽 W(width)和体质量 TW(total weight)等 3 个性状进行测定,并计算 1 个复合形态指标 SLW (square root of the length-width,$\sqrt{L \times W}$)。方法如下:将紫刺参样本吸取体表水分后沥水 10 min,用电子天平测量体质量,精确至 0.01 g;参考韩莎等[12]的方法,将紫刺参放入 0.2 mol · L^{-1} 的薄荷醇溶液中麻醉 5 ~10 min,待其身体放松呈舒展状态时,用相机对样本进行拍照,通过 camera measure 软件进行图像计算获取体长、体宽数据;体长是指从背部触手前端到肛门的曲线长度,体宽是指背部正中的宽度,精确到 0.01 cm。理论体长 Le (estimated length)由 SLW 转换而来,对体长和 SLW 进行线性回归,得到方程为:$Le = a + b\text{SLW}$。

1.2　数据分析

1)描述性统计

通过 SPSS 软件对紫刺参形态性状(L, W, SLW)和体质量进行分析,结果均用平均值 ± 标准差(mean ± SD)表示;对样本数据进行 KS-检验,是否符合正态分布(表 1)。计算变异系数 CV (coefficient of variability)和条件因子,相关计算式为:CV = 标准差/平均值 × 100%,条件因子(condition factor) = TW/L^3。采用频率分析法绘制 L、W、SLW、TW 和条件因子频率直方图。

2)模型拟合分析和筛选

利用 10 种模型(线性模型 Linear、对数曲线模型 Logarithmic、反函数曲线模型 Inverse、二次曲线模型 Quadratic、三次曲线模型 Cubic、幂函数模型 Power、S 曲线模型 S curve model、增长曲线模型 Growth、指数曲线模型 Exponential、逻辑斯蒂曲线模型 Logistic)对各形态性状与体质量的关系进行回归分析和曲线估算,计算各模型的参数估计值,以拟合度 r^2 的大小作为判断形态性状和体质量关系的评价标准(一般 r^2 >0.70 确定为最优),选取最优形态性状,建立形态性状-体质量关系。

3)异速生长分析

异速生长方程采用 $y = ax^b$ 表示,其中自变量 x 为形态特征值,因变量 y 为体质量;a 为条件因子,b 为异速生长因子,当 $b = 3$ 为等速生长,$b > 3$ 为正异速生长,$b < 3$ 为负异速生长,用 t 检验比较差异显著性($P < 0.05$)。

2　结果与分析

2.1　紫刺参群体结构

个体大小差异大是海参的普遍特征[13],但目前关于刺参个体生长差异的机理研究甚少[14-16]。个体生长变异多受密度、遗传和等级行为[17]等因素的影响,在养殖条件下,水温相对稳定,饵料充足,放养密度合适,影响刺参个体生长差异的遗传因素远大于其他因素。DONG 等[14]研究表明,在食物持续稳定供应的情况下,群体养殖刺参个体体质量变异超过 70%。由表 1 可见,紫刺参各性状的 CV 不等,在 31.52% ~66.85%波动,其中体质量的变异系数最大,为 66.85%,远高于鱼类、虾类体质量变异系数(20% ~30%)。

表 1　紫刺参性状的描述性统计

Tab.1　Descriptive statistics of characters of *A. japonicus*(purple sea cucumber)

性状 Character	极小值 Min	极大值 Max	平均值 ± 标准差 Mean ± SD	变异系数/% CV
体长(L)/cm Body length	0.88	21.39	10.70 ± 3.58	33.46
体宽(W)/cm Body width	0.81	5.25	2.68 ± 0.91	33.92
SLW/cm	1.62	10.05	5.32 ± 1.68	31.52
体质量(TW)/g Total weight	1.92	151.87	50.94 ± 34.05	66.85

紫刺参群体的形态性状、体质量和条件因子频率分布如图 1 所示。4 个生长性状和条件因子分布形态均为不对称分布(偏度值≠0),偏度值为 0.17 ~ 1.59,呈右偏,其中,条件因子偏度值最大,其次为体质量,偏度值最小的为体长。3 个形态性状和体质量数据分布形态为平峰分布(峰度值<0),峰度值为 -0.13 ~ -0.37,数据分布平缓,而条件因子分布形态为尖峰分布,峰度值为 3.14,数据分布更为陡峭,平均值为 4.57 ±4.06。刺参体长频率分布可以反映其群体结构,分布形态有单峰、双峰和多峰[18]等多种形态,本研究显示,紫刺参养殖群体体长频率分布呈现为单峰,与糙海参(*Holothuria scabra*)野生群体[19]一致。

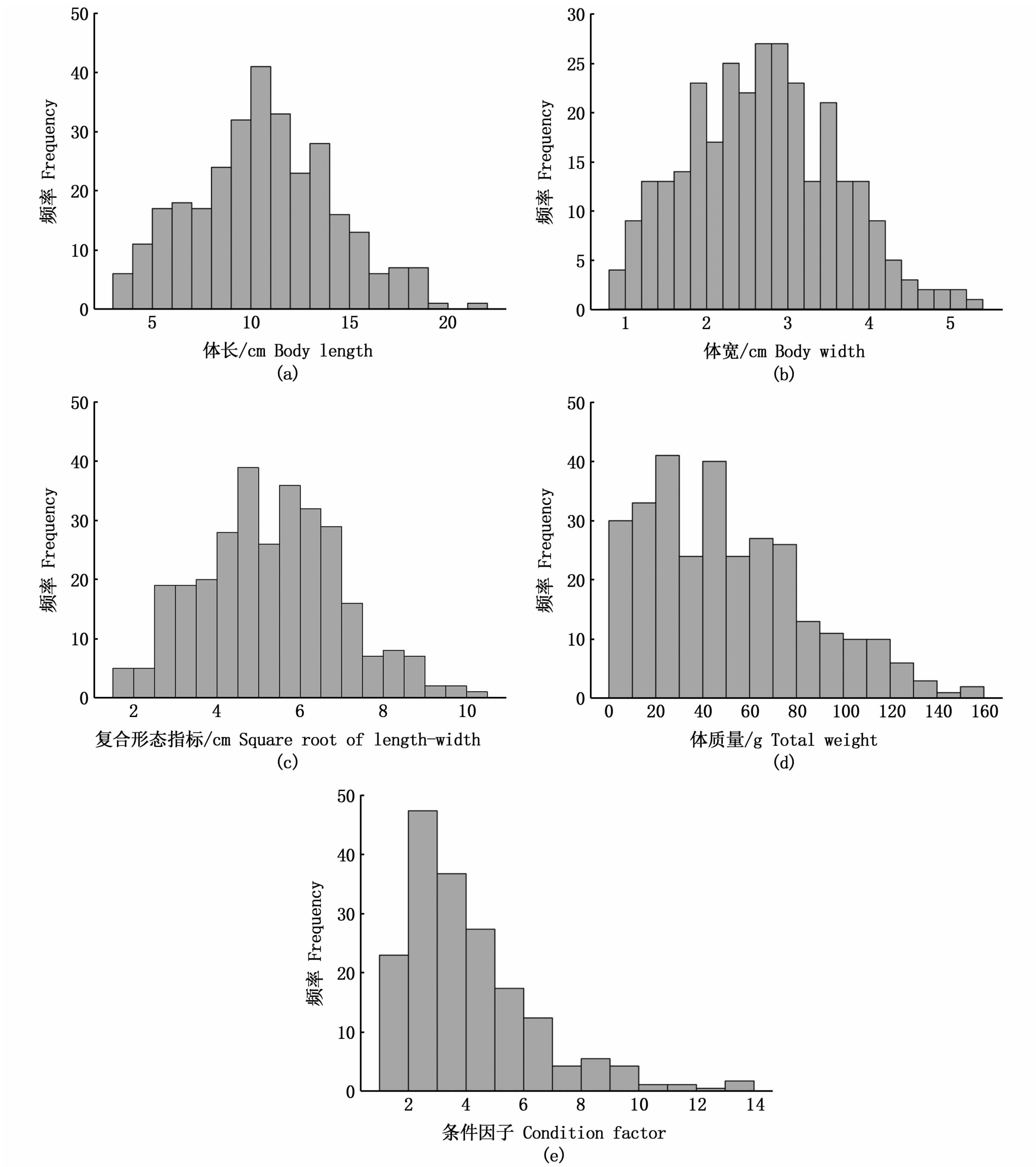

图 1 紫刺参体长、体宽、SLW、体质量和条件因子频率分布

Fig. 1 Frequency distributions of body length, body width, square root of length-width, total weight and condition factor for *A. japonicus*(purple sea cucumber)

2.2　紫刺参形态性状和体质量关系模型的选择

水产动物体长-体质量关系的拟合模型有线性模型、幂函数模型、指数函数模型等,因种类、性别、生长阶段的不同,适用的模型也存在差异。本研究利用 10 种模型分别对 3 组形态性状 L、W、Le 和 TW 的关系进行回归分析,各模型参数估计和拟合精度如表 2 ~ 表 4 所示。一般将 $r^2 > 0.70$ 作为确定为最优模型的评价标准,由表可见,紫刺参各形态性状与体质量关系最优拟合模型均为幂函数模型,r^2 分别为 0.75、0.69 和 0.84,该结果与其他海参类[19]、鱼类[20]、虾类[21]等研究一致。

选取合适的形态指标是确定形态性状与体质量关系的前提,刺参外部形态体呈圆筒状,两端稍细,中间粗[22],体壁中部增厚高于前部和后部。对于细长型的物种来说,衡量体质量的重要指标不仅仅是长度[23],体宽同样是影响刺参体质量的重要形态性状。POOT-SALAZAR[7]提出运用复合形态指标 SLW 降低形态数据的变异性,通过间接方法计算美国肉参(*Isostichopus badionotus*)的生长参数而获取的形态性状与体质量关系更为准确,体质量评估准确度提高了 80%。本研究结果发现,紫刺参体长-体质量、体宽-体质量关系拟合度接近,而理论体长-体质量关系具有更高的拟合度和相关性。由此可见,理论体长 Le 是描述紫刺参形态性状与体质量关系的最优形态指标。Le 这一复合形态指标综合了体长和体宽,能够有效控制因紫刺参身体收缩而引起的形态数据的离散,在暗色等刺参(*Isostichopus fuscus*)[9]、沙海参(*Holothuria arenicola*)[11]等形态性状-体质量研究中均采用形态指标 Le,并得出了相同的结论。Le 与 SLW 的回归方程为 $Le = 0.60 + 1.90SLW$($r^2 = 0.79$, $P < 0.05$)。

表 2　紫刺参体长与体质量关系的模型分析与参数估计

Tab. 2　Summary and parameters of relationship between body length and total weight of *A. japonicus* (purple sea cucumber)

模型 Model	模型分析 Model analysis					参数 Parameters			
	r^2	F	df_1	df_2	Sig.	Con.	b_1	b_2	b_3
线性模型 Linear	0.66	587.45	1	299	0.000	−31.90	7.74		
对数曲线模型 Logarithmic	0.60	447.52	1	299	0.000	−111.14	70.26		
反函数曲线模型 Inverse	0.46	258.74	1	299	0.000	102.75	−481.52		
二次曲线模型 Quadratic	0.67	295.98	2	298	0.000	−20.89	5.49	0.10	
三次曲线模型 Cubic	0.67	202.76	3	297	0.000	17.61	−7.16	1.33	−0.04
幂函数模型 Power	0.75	882.34	1	299	0.000	0.39	1.99		
S 曲线模型 S curve model	0.71	723.56	1	299	0.000	5.26	−15.09		
增长曲线模型 Growth	0.69	665.57	1	299	0.000	1.49	0.20		
指数曲线模型 Exponential	0.69	665.57	1	299	0.000	4.45	0.20		
逻辑斯蒂曲线模型 Logistic	0.69	665.57	1	299	0.000	0.23	0.82		

表 3　紫刺参体宽与体质量关系的模型分析与参数估计

Tab. 3　Summary and parameters of relationship between body width and total weight of *A. japonicus* (purple sea cucumber)

模型 Model	模型分析 Model analysis					参数 Parameters			
	r^2	F	df_1	df_2	Sig.	Con.	b_1	b_2	b_3
线性模型 Linear	0.68	623.11	1	299	0.000	−31.59	30.72		
对数曲线模型 Logarithmic	0.61	466.94	1	299	0.000	−15.04	71.40		
反函数曲线模型 Inverse	0.48	280.81	1	299	0.000	106.57	−130.11		
二次曲线模型 Quadratic	0.68	321.04	2	298	0.000	−12.21	15.13	2.80	
三次曲线模型 Cubic	0.68	214.15	3	297	0.000	2.28	−3.22	9.70	−0.79
幂函数模型 Power	0.69	658.69	1	299	0.000	6.42	1.92		
S 曲线模型 S curve model	0.64	525.50	1	299	0.000	5.26	−3.79		
增长曲线模型 Growth	0.66	569.82	1	299	0.000	1.58	0.77		
指数曲线模型 Exponential	0.66	569.82	1	299	0.000	4.83	0.77		
逻辑斯蒂曲线模型 Logistic	0.66	569.82	1	299	0.000	0.21	0.46		

表 4 紫刺参理论体长与体质量关系的模型分析与参数估计

Tab. 4 Summary and parameters of relationship between estimated length and total weight of *A. japonicus* (purple sea cucumber)

模型 Model	模型分析 Model analysis					参数 Parameters			
	r^2	F	df_1	df_2	Sig.	Con.	b_1	b_2	b_3
线性模型 Linear	0.78	1 079.27	1	299	0.000	−44.67	17.99		
对数曲线模型 Logarithmic	0.71	732.89	1	299	0.000	−83.49	83.21		
反函数曲线模型 Inverse	0.57	393.63	1	299	0.000	115.97	−306.86		
二次曲线模型 Quadratic	0.79	560.48	2	298	0.000	−23.32	9.35	0.79	
三次曲线模型 Cubic	0.80	385.20	3	297	0.000	21.42	−19.15	6.26	−0.32
幂函数模型 Power	0.84	1 600.20	1	299	0.000	0.93	2.30		
S 曲线模型 S curve model	0.81	1 285.08	1	299	0.000	5.61	−9.30		
增长曲线模型 Growth	0.78	1 084.74	1	299	0.000	1.21	0.46		
指数曲线模型 Exponential	0.78	1 084.74	1	299	0.000	3.36	0.46		
逻辑斯蒂曲线模型 Logistic	0.78	1 084.74	1	299	0.000	0.30	0.63		

2.3 紫刺参异速生长规律分析

异速生长是指在相对生长速率上生物体的某一种特征与另外一种特征存在差异,这种现象广泛存在于动植物的生长过程中[24]。据研究,体长-体质量关系中,b 值的不同除受物种间内在遗传差异因素影响外,还与个体营养状况及生长环境等外界因素有关[25]。水产动物异速生长因子 b 值主要分布在 2.5~3.5;而海参类生长缓慢,其 b 值分布范围较广,为 0.65~2.95[10],异速生长因子 b 均小于 3。本研究紫刺参异速生长方程为:$y=0.93x^{2.30}$($r^2=0.84$)(图 2),异速生长因子 b 为 2.3($P<0.05$),表明 24 月龄紫刺参群体呈负异速生长模式($b<3$),反映了紫刺参生长发育过程中形态性状和体质量发育的不均性,即形态性状的生长快于体质量的增加,这与大多数海参生长特性的研究结果一致[26]。刺参形态呈细长型或粗短型,因其体长的增长和体壁的增厚并非同步进行,这就造就了同一种刺参形态各异。野生刺参生长慢,形态粗短,养殖刺参生长快,形态细长。研究表明,条件因子大于 1 时,表明营养条件是合适的[23],本研究中养殖紫刺参条件因子远远高于野生刺参,这是因为野生刺参的食物丰度依赖于生境条件,而养殖刺参营养充足,这一点也说明营养条件是影响刺参生长快慢的重要因子之一,而且营养条件对紫刺参规格的贡献占相当大的比重。

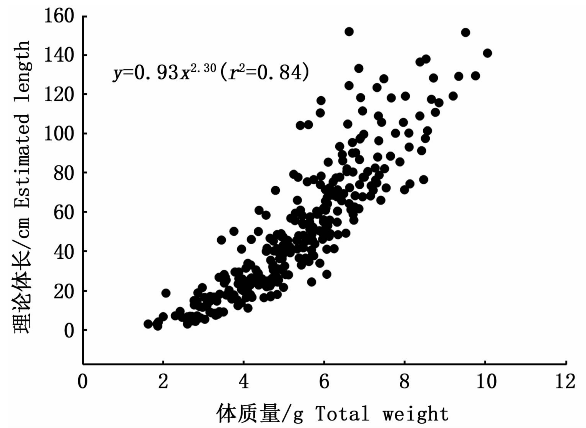

图 2 紫刺参理论体长-体质量关系

Fig. 2 Relationship between estimated length and total weight of *A. japonicus* (purple sea cucumber)

3 小结

紫刺参属于暖温性物种,生长缓慢且具有阶段性,通常至少要 2 年以上才能达到商品参规格。本研究发现,紫刺参各形态性状与体质量关系的最优拟合模型为幂函数模型,理论体长 Le 是描述紫刺参形态性状与体质量关系的最优形态指标。24 月龄紫刺参大部分个体仍处于快速生长阶段,为负异速生长模式,紫刺参形态性状的增长快于体质量的增加。

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Morphometric correlation and regression of morphometrical traits and total weight of 24-month-old *Apostichopus japonicus* (purple sea cucumber)

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Abstract: Sea cucumber *Apostichopus japonicus* is one of the most commercially important mariculture species in China. In recent years, the market requirement and consumption of sea cucumbers have gradually increased. Therefore, the sea cucumber farming industry has been developping rapidly and become the pillar industry of coastal fishery economic in China, especially in the north China. Although the development of sea cucumber industry is rapid, several issues are demanding prompt solutions, such as lack of basic biology research, germplasm degradation, slow growth and reduced stress resistance of the existing varieties. Compared with other aquaculture species, special varieties with high-quality economic characteristics are few, and the lack of improved varieties in sea cucumber restricts the development of farming industry. Therefore, germplasm creation has become one of the key points of sea cucumber farming research.

At present, new varieties of sea cucumber have been selected and bred successively with excellent economic characteristics, such as fast growth rate, high temperature resistance and disease resistance after great effort of breeding research institutes and production units for many years. It has laid the germplasm foundation for the further development of the sea cucumber industry in China. *A. japonicus* (purple sea cucumber) is a kind with special skin characteristic of sea cucumber. These high-quality strains will lay the foundation for the diversification of sea cucumber species.

Accurate size measurements are important for the determination of growth performance for aquaculture. Most methods are used to estimate growth through length frequency data analysis, which depends on body measurements and biometric relationship. It is very difficult to measure the growth characteristics of sea cucumbers because of the difficulty in determining age by stress and dirty discharge, water spitting after leaving water, and body stretching and deformation. Precise measurements of body weight and body length in sea cucumber are challenging under different conditions. The body length of sea cucumbers can change considerably by elongation or contraction, and the body weight also varies considerably depending on the amount of water in respiratory trees and the intestinal content. Body size and body weight relationship is also important in determining the nutritional condition of the organisms. At the moment, there are no standard evaluation methods for accurate measurement of sea cucumber. In addition, compound indices that combine different biometric parameters can be applied to generate more precise biometric relationships.

The study was conducted to explore morphometric correlation of morphometrical traits and body weight of 24-month-old *A. japonicus* (purple sea cucumber). 300 individuals were selected and relaxed by placement in containers with menthol of 0.2 mol · L^{-1} for 5 to 10 min. Then boby length (L), body width (W) and total weight (TW) were measured for each individual. When the body was relaxed and stretched, the camera was used to take pictures of the samples, and the data of body length and width were obtained by image calculation with camera measure software. Body length was measured from the center of the tentacle crown to the anus (curved length). Body width was measured dorsally at the widest point. Total weight was measured with a digital balance, accurate to 0.01 g. Indirect methods were used to estimate the growth by use of compound index. A compound index that combined body length and body width to produce SLW index ($\sqrt{L \times W}$) and its transformation Le were utilized to obtain more precise biometric relationships. Length-weight relationship was evaluated and the optimal fitting morphometrical traits and curve model were also selected by regression analysis.

Results showed that the coefficients of variability of growth characters were 31.52%-66.85% and the highest and lowest character was body weight and SLW, respectively. The regression analysis results of the best fitting model of morphometrical traits and body weight were all power function model and Le was the best fitting morphological parameter for length-weight relationship. Biometric relationship was useful to carry out transformations of body length to total weight. Body length and weight relationship have not been established for all sea cucumber species. First study applying a compound index on *A. japonicus* (purple sea cucumber) was accomplished. Body length, as well as body width, was also an important morphometrical trait. Therefore, it could be assumed that recalculated length from SLW might be useful to get accurate body length of sea cucumber. This study established indirect method for estimation of total weight in *A. japonicus* (purple sea cucumber). Using estimated body length (Le) from the compound index SLW enhanced weight estimation accuracy in this study. The SLW compound index could reduce the variability of body length to homogenize the samples, facilitating the calculation of growth parameters by indirect method.

A power model was used in the weight regression of *A. japonicus* (purple sea cucumber), and a strong correlation was found between weight and SLW. The 24-month-old *A. japonicus* (purple sea cucumber) grew allometrically with negative allometry tendency. It grew rapidly with better performance of morphological traits than body weight. The relationship among morphological traits at different development stages was unclear, neither the impacts of morphological variation on economically important traits at different stages. This study developed an algorithm to estimate *A. japonicus* (purple sea cucumber) weight by measuring its feature, including body length and body width. The indirect method and Le-weight regression models in this study may be useful in growth evaluation of *A. japonicus* (purple sea cucumber). The results of this paper provide theoretical guidance for growth and cultivation for *A. japonicus* (purple sea cucumber).

Keywords: *Apostichopus japonicus* (purple sea cucumber); size-weight relationship; morphometrical traits; total weight