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不同饵料条件下玉筋鱼摄食、生长和生态转换效率的比较

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摘要:将Eggers模型移入实验室大型玻璃钢水槽中,采用3种室内可能得到的实验饵料:冷冻细脚长蛾(*Themisto gracilipes*)、天然成体卤虫(*Artemis salina*)和小黄鱼糜(Fish silage),在流水条件下,比较黄渤海主要中上层小型鱼类玉筋鱼(*Ammodyte personatus*)对上述3种饵料的摄食、生长和生态转换效率等生态能量学特征。结果显示,3种饵料中,虽然玉筋鱼对细脚长蛾的能量生态转换效率较高,但是其湿重摄食量[g/(100g·d)FW]和能量摄食量[kJ/(100g·d)]都比较低,生长情况较差;卤虫的食物生态转换效率较高,湿重摄食量较多,生长情况较好;鱼糜的能量摄食量较多,生长情况介于两者之间,但其生态转换效率均较低。与自然生长的玉筋鱼相比,摄食卤虫的玉筋鱼较接近于自然生长。研究结论认为,室内玉筋鱼的模拟实验,在不能获得自然活体饵料的情况下,卤虫不失为一个理想的选择。

关键词:摄食;生长;生态转换效率;饵料;玉筋鱼
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渔业资源的过度开发,使资源遭破坏,资源质量下降,资源结构发生变化。传统的经济鱼类逐渐被一些低等、生长速度快的小型鱼类所代替,并且这些小型鱼类逐渐演变为黄渤海的鱼类生物资源主体[1]。近几年鱼类资源调查和渔业数据统计结果显示,玉筋鱼(*Ammodyte personatus*,Girard)的资源量大幅度上升,捕捞量由1998年的15万t迅速上升到1999年的50万t,成为该海域继鳀鱼(*Engraulis japonicus*)之后最大的渔业资源[2]。玉筋鱼为浮游生物食性的小型鱼类,其摄食的浮游生物种类多、范围广[3],同时它又是许多大中型鱼类的重要饵料生物,在黄渤海食物网结构中扮演着重要角色。对玉筋鱼的生态能量学进行研究,将为定量黄渤海食物网物流、能流动力学过程和建立生态系统动力学模型,提供重要的基础资料。

玉筋鱼属中上层小型鱼类,极易受伤死亡,故其活体获取非常困难,这种鱼的室内驯养和研究工作较少开展。自从李军等[4]对铺沙养玉筋鱼的方法进行探讨后,为玉筋鱼的室内个体研究奠定了基础。杨纪明等[5]应用室内个体方法研究了包括玉筋鱼在内的一个简单食物链能量流动,即金藻→卤虫→玉筋鱼→黑鲪(*Sebastodes fuscescens*);孙耀等[6]则以卤虫幼体为饵料,应用室内群体条件下的胃含物法进行了玉筋鱼生态能量学方面的研究。玉筋鱼的自然饵料不包含卤虫,因此采用卤虫作为其饵料是否合适,是决定室内玉筋鱼模拟实验是否有实际意义的关键性问题。本实验采用室内可能获得的3种典型饵料,进行玉筋鱼的生长实验,旨为对此问题进行探讨并提供实验证据。

1 材料与方法

1.1 材料

实验在中国水产科学研究院黄海水产研究所的青岛市麦岛实验基地进行,所用玉筋鱼均是在该实验基地近岸海域用定置网捕获而得。为降低玉筋鱼的受损伤亡率,尽量简化捕获玉筋鱼至室内驯养的中间过程,避免离水操作。将捕获的玉筋鱼转移至室内大型玻璃钢水槽内,在实验条件下驯养约1周,待存活率稳定、摄食正常后,开始正式实验。

1.2 实验设计

将玉筋鱼移入室内2.5 m^3的玻璃钢水槽中,在流水条件下进行驯养实验。水槽内流水速率的调

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节,以槽内水体的主要化学指标与自然海水无显著差别为准,一般流速不低于24 m^3/d。实验海水经过沉淀和沙滤处理后输送到各实验水槽。实验在水温(20.40±0.95) ℃下进行,实验中采用自然光照周期(2002年6月1日至2002年6月21日),最大光强为250 lx。收集实验前后玉筋鱼样品和3种投喂饵料样品,经70 ℃低温烘干、粉碎和过20目套筛后,进行能值测定;能值采用热量计(XYR-1)测定。实验采样用10%的福尔马林溶液进行固定。样品称重采用压电式单盘电子天平(Model BP221S,Sartorius),其最大称重量220 g,称量精密度±0.000 1 g。

1.3 饵料及投喂方法

投喂的饵料有3种:一种是用细网目定置网具在麦岛近海捕获,经-20 ℃冷冻保存的细脚长蛾;一种是天然成体卤虫;另一种是小黄鱼糜。每天6:00和16:00投饵2次,在实验水体中始终保持过量饵料生物。

1.4 胃含物测定

目前使用较多的胃含物模型为Eggers[7]模型和Elliott-Persson[8]模型。这2种模型具有同等的准确性[9],而Eggers模型具有取样次数相对较少,既能简化实验操作,又能减少对实验鱼的干扰,故本实验采用Eggers[7]模型。每间隔5 d进行1次,共做5次;每次24 h连续取样,取样间隔时间为3 h;取样量为每次20尾;取样后立即用福尔马林溶液固定,待实验结束后再对其体长、体重和胃含物重量等数据进行测定。

因玉筋鱼的个体偏小,故胃含物用全消化道内含物代之。取被固定的鱼类样品,测定其体长、体重和消化道内含物重量。消化道内含物的定量方法如下:取出整个消化道(包括食道、胃、肠道),用吸水纸吸干水分后称湿重,然后洗去消化道内食物,再称取空消化道重量,两个重量之差即为消化道内含物重量。

1.5 排空率测定

在胃含物测定实验过半时,插入排空率实验。取饱食后实验鱼80尾,置于洁净的玻璃钢水槽内进行排空率实验;该实验海水经脱脂棉和300目筛绢再过滤后进入水槽。实验自玉筋鱼移入始,每间隔1小时取样5尾,共取11次(注:卤虫排空实验时因损伤较大,只取了9次),每次取样后立即用福尔马林溶液固定,固定样品待实验后再测,测定方法同上。

常用的鱼类胃排空模型有:线性模型[11-12]、平方根模型[13]和指数模型[7,14]等。指数模型是用的最普遍的一种[15-16],它比其他模型能更好地描述鱼类的胃排空[17],且当鱼类捕食小型、低能的食物时尤其适用[18],因此本实验采用了指数模型来描述玉筋鱼的胃排空速率。

1.6 计算方法

日摄食量按Eggers[7]公式 $C_d = 24 \times S \times R_t$ 进行估算,式中,S 为24 h内平均全消化道内含物量;R_t 为瞬时排空率,以瞬时全消化道内含物量的自然对数值与所对应排空率实验时间进行线性回归,回归方程的斜率即为 R_t 值。日生长量(G_d)是将实验期间玉筋鱼的重量变化与所对应的时间进行线性回归,该回归方程的斜率就是 G_d 值。生态转换效率则可以由公式 $E_g = (G_d/C_d) \times 100\%$ 求得[10]。

2 结果与分析

2.1 实验生物的水分及能值

玉筋鱼和投喂饵料的水含量和干物质能含量的测定结果见表1。

表1 玉筋鱼和投喂生物的水含量及能含量

Tab.1 Water and energy contents in *Thryssa kammalensis* and feed organisms

生物种类 Biologic species	水分/% Moisture	能含量/($kJ \cdot g^{-1}$DW) Energy content
玉筋鱼 *Ammodyte personatus*	78.48	19.00
细脚长蛾 *Themisto gracilipes*	91.57	11.94
卤　虫 *Artemis salina*	86.16	13.56
鱼　糜 Fish silage	75.09	18.70

2.2 排空率

玉筋鱼对3种饵料瞬时全消化道内含物量与时间之间的关系,即排空曲线,如图1所示。描述图1曲线的回归方程、统计参数、排空率的测定参数及结果见表2。

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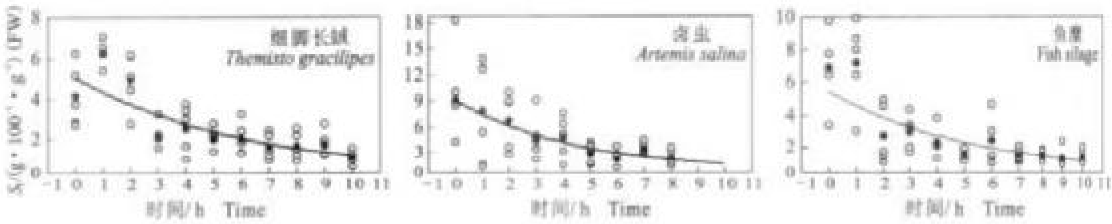

图 1 玉筋鱼投喂不同饵料条件下的排空曲线

S_t:消化道食物含量; ●:食物含量均值; ○:食物含量采样值.

Fig. 1 Gastric evacuation curves in sandlances fed with three different kinds of food

S_t:food content in gut; ●:average food content; ○:sampling food content.

表 2 玉筋鱼不同饵料条件下排空率的测算参数

Tab. 2 Determined and calculated parameters of the evacuation rate with three different kinds of food

饵料种类 Food species	测定尾数 N	体重/g(FW) Body weight	回归方程 Regression equation	R_t	R^2	P
细脚长蛾 *Themisto gracilipes*	55	0.90±0.30	$S_t=5.0314e^{-0.1493t}$	0.1493	0.8248	<0.01
卤 虫 *Artemis salina*	45	0.90±0.30	$S_t=9.0757e^{-0.1887t}$	0.1887	0.8664	<0.01
鱼 糜 Fish silage	55	0.81±0.29	$S_t=5.4579e^{-0.1746t}$	0.1746	0.8052	<0.01

注:R_t 为瞬时排空率;R^2 为相关指数,测定水温 21 ℃.

Note: R_t—instantaneous evacuation rate; R^2—*relation index*; water temperature 21 ℃.

2.3 日摄食量估算

根据本实验中不同时期玉筋鱼全消化道 24 h 平均食物含量的实测值,及 2.2 中所估算出的瞬时排空率 R_t 值,按 Eggers 公式可求得各实验时期玉筋鱼的湿重平均日摄食量(表 3);再据表 1 所列饵料生物细脚长蛾、卤虫、鱼糜的水分含量及干物质能含量值,可以求出以能值为单位的平均日摄食量(表 4)。可以看到,3 种饵料中不管是以湿重还是以能量计的平均日摄食量,细脚长蛾的值都最低,卤虫的最高。由于投喂方式保证了玉筋鱼可以获得充足的饵料,所以这些结果可认为是其最大日摄食量。

表 3 3 种饵料条件下的玉筋鱼全消化道 24 h 平均食物含量和日摄食量(2002 年)

Tab. 3 Daily average contents in stomach and daily rations fed with three different diets(2002) FW

饵料 Food species	项目 Item	日期 Data 1 June	6 June	11 June	16 June	21 June	平 均 Average
细长脚蛾 *T. gracilipes*	BW/g	0.4534±0.1720	0.5277±0.2309	0.6702±0.2330	0.6685±0.2504	0.7084±0.2753	0.5756±0.2452
	S_t	3.8465±2.6805	4.2149±3.0366	4.9607±2.2397	4.8430±2.7564	2.9390±1.8725	4.2033±2.6961
	C_d	13.7827	15.103	17.775	17.3535	10.5309	14.909
卤 虫 *A. salina*	BW/g	0.4161±0.1422	0.5630±0.2274	0.7629±0.2094	0.7873±0.2523	1.1206±0.3077	0.6816±0.3267
	S_t	4.4833±3.3874	6.6562±4.5137	5.4326±3.6926	3.7120±2.71491	0.1233±6.2536	5.9297±4.6678
	C_d	20.3039	30.1447	24.6033	16.811	45.8466	27.5419
鱼 糜 Fish silage	BW/g	0.5041±0.1628	0.5596±0.2298	0.6901±0.2397	0.7854±0.2037	0.8378±0.1124	0.6317±0.2336
	S_t	4.6315±3.7291	4.0121±2.4885	7.8873±5.0438	4.0481±3.1972	4.2768±2.1573	4.8927±3.7610
	C_d	19.4078	16.8122	33.051	16.963	17.9214	20.8311

注:S_t—消化道食物含量/(g·100^{-1}·g^{-1}) (FW);C_d—日摄食量/(g·100^{-1}·g^{-1})(FW).

Note: S_t—food content in gut/(g·100^{-1}·g^{-1})(FW); C_d—daily food consumption/(g·100^{-1}·g^{-1})(FW).

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2.4 日生长量及生态转换效率

对玉筋鱼摄食量测定期间其体重变化与对应的时间进行线性回归分析,二者之间的关系可用线性方程定量描述:

细脚长䗛:$W_t=0.0128t+0.477$,

$R^2=0.8708, N=5, P<0.01$

卤虫:$W_t=0.0325t+0.403$,

$R^2=0.9406, N=5, P<0.01$

鱼糜:$W_t=0.0178t+0.497$,

$R^2=0.9785, N=5, P<0.01$

式中,W_t为鱼体重,t为投喂时间(h)。由上述方程式可求得不同饵料条件下玉筋鱼的平均日生长量(G_d)。由于已知玉筋鱼的平均日摄食量,按公式$E_g=(C_d/G_d)\times100\%$可求得其生态转换效率(E_g),结果如表4所列。比较可以看出,投喂细脚长䗛的玉筋鱼生长最缓慢,而投喂卤虫的玉筋鱼生长最快;投喂细脚长䗛的玉筋鱼能量生态转换效率最高,而投喂卤虫的食物生态转换效率最高。

表4 玉筋鱼不同饵料条件下的摄食、生长和生态转换效率

Tab.4 Food consumption, growth and conversion efficiency of sandlance with three different kinds of food

饵料种类 Food species	C_d g/(100g·d)FW	C_d kJ/(100g·d)	G_d g/(100g·d)FW	G_d kJ/(100g·d)	E_g %(FW)	E_g %(kJ)
细脚长䗛 *Themisto gracilipes*	14.91±2.94	15.00±2.96	2.22	9.09	14.92	60.59
卤虫 *Artemis salina*	27.54±11.38	51.72±21.37	4.77	19.50	17.31	37.69
鱼糜 Fish silage	20.83±6.91	97.01±32.17	2.82	11.52	13.53	11.87

注:C_d—日摄食量;G_d—日生长量;E_g—生态转换效率。
Note: C_d—food consumption per day; G_d—growth per day; E_g—conversion efficiency.

3 讨论

实验采用了冷冻细脚长䗛、自然成体卤虫、鱼糜3种饵料,这些饵料都是在室内实验条件下可能采用的几种典型饵料。玉筋鱼是以浮游动物为主要食物的海洋小型鱼类,细脚长䗛是其所食天然浮游动物的主要品种之一[19],选择细脚长䗛作饵料接近玉筋鱼的自然状况。采用活体细脚长䗛是最理想的选择,但因是群体实验,周期较长,难以保证足量的活体细脚长䗛,所以只能采用冰冻的细脚长䗛来投喂。在中国海洋鱼类苗种人工培育中,幼体卤虫通常被用作前期饵料,也常常被用来作为小型鱼类的实验饵料[20-23],用幼体卤虫作为饵料的生长实验在前一年的同时期已经做过;本实验所采用的卤虫是盐场自然生长的成体卤虫,旨为进行成体与幼体卤虫的比较。鱼糜是一般养殖生产企业常用的饵料,它的制作工艺简单,获取方便,因此也常被室内实验所采用[23-25]。

从本实验结果(表4)可见,投喂冰冻细脚长䗛的摄食状况欠佳,摄食量最少,生长情况也最差;摄食鱼糜的玉筋鱼摄食量虽然较高,但其生态转换效率不管是按湿重还是按能量计算在3种饵料中都是最低的;投喂卤虫的玉筋鱼摄食状况良好,生态转换效率较高,生长情况最好。实验中观察发现,投喂卤虫的玉筋鱼体色呈浅黄色,体态大而饱满,活动敏捷,摄食迅猛;而投喂另外两种饵料的玉筋鱼体色黯黑,体形瘦小,反应迟钝,摄食不积极。实验的同时,在野外捕获一批自然条件下生长的玉筋鱼,把室内玉筋鱼的生长与它们进行了比较(图2),投喂两种卤虫的玉筋鱼丰满度比投喂其他两种饵料的更接近自然情况。通过上述比较明显看出,卤虫是此3种饵料中最适合投喂玉筋鱼的饵料。

按常规,玉筋鱼摄食自然饵料的生长应好于替代饵料[26],导致本实验不同结果的原因可能有两方面。首先,未采用细脚长䗛活体是其主要原因,冰冻的细脚长䗛大大影响了玉筋鱼的摄食;其次,冰冻的细脚长䗛在解冻过程中流失了许多有机质,减少了营养成分,不利于玉筋鱼的生长。因此室内玉筋鱼实验在没有自然活体饵料的情况下,投喂卤虫是一种较好的选择。另外与投喂幼体卤虫生长比较,摄食成体卤虫的玉筋鱼更接近自然(图2),可见成体卤虫比幼体卤虫更合适于投喂玉筋鱼。

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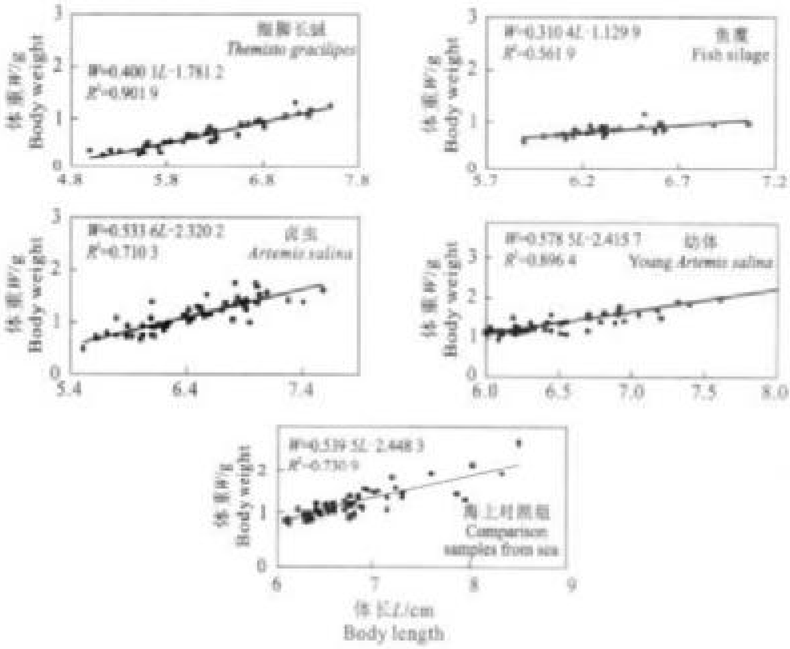

图2 3种不同饵料投喂下玉筋鱼的生长情况与自然生长情况的比较

Fig.2 Growth comparison between nature and sand lances fed with three different kinds of food in lab

不论是相对摄食率、相对生长率还是食物生态转换效率,摄食卤虫的值都要比摄食细脚长𧊕的要高。但是能量生态转换效率的情况却相反,湿重为参数的生态转换效率容易受到其他因素的影响[27-28],而以能量为参数,可以较稳定地反应事物的实质。玉筋鱼摄食细脚长𧊕的能量转化成身体有机质能量的比例相比卤虫要高,这个结果表明,细脚长𧊕确实是玉筋鱼的天然饵料,它能使各个食物层次之间的生态转换效率达到最优状态,这是生态平衡的最终选择结果[29]。

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Comparison of food consumption, growth and conversion efficiencies among sandlance (*Ammodyte personatus* Girard) fed with different kinds of food

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Abstract: This experiment was conducted in Qingdao Maidao Experiment Base of Yellow Sea Fisheries Research Institute, Chinese Academy of Fishery Sciences. The sandlances (*Ammodyte personatus* Girard) in the experiment were caught by fixation net from alongshore sea area. After being transferred into large steel-glass tanks in lab, the fish were domesticated for about one week. The water in tanks was flowing, and its velocity was not less than 24 m^3/d based on the guideline that the water chemical target could be similar to that of the nature. The sea water was deposited and sieved by sand firstly, and then were transferred to tanks. The average water temperature was (20.40 ± 0.95) ℃. Whole experiment was under nature light cycle. After the fish had been adapted to the environment, the experiment started. During the experiment the fish were fed with three kinds of food, ie. *Themisto gracilipes*, *Artemis salina* and fish silage, which were accessible under lab conditions. They were fed everyday twice at 6:00 and 16:00 to overmuch so as to ensure the ecological energetic parameters of sandlance could be got under the largest food consumption condition. Gastric content sampling method in field was transformed in lab. For each measurement 20 samples were collected at 3-hour intervals, and this measurement period was 24 h. This experiment was conducted every 5 d, and there were 5 times in total. At the middle of this experiment, gastric evacuation experiment was made. Five samples were taken every one hour, and there were 11 sampling times totaly. In all of above experiments, when sandlances were sampled, they must be put into formalin solution immediately to be fixed. The parameters, such as body length, body weight, gastric food content and so on were measured after all these experiments were finished. Since sandlance body was so small, gastric food content was substituted by whole gut food contents. The gut food contents were measured by following steps: first, the whole gut including gullet, stomach and intestine were weighed up after dried by absorb-water paper; second, they were weighed up again after the food in it was cleaned up; last the gut food contents could be got by the difference

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between above two weights. In data treatment, the selected gastric evacuation model was exponential model because it was better to describe the gastric evacuation of fishes, and it was the most appropriate for those fishes which always eat small, low energy foods. Because it needed less samples, simple operation and had little disturbances to fishes, Eggers' model was adopted. Daily food consumption(C_d) was calculated by Eggers' equation $C_d = 24SR_t$, where S meant 24 h gut food contents and R_t meant instantaneous evacuation rate; daily growth was the slope of the regressing equation which was got from regression between body weight and time; conversion efficiency(E_g) was calculated by equation $E_g = (G_d/C_d)$ 100%, where G_d meant equation regression. Food consumption, growth and conversion efficiency were compared among different feed groups. The results indicated that the conversion efficiency of energy in sandlance fed with *Themisto gracilipes* was the highest, but the highest conversion efficiency of day matter was that of sandlance fed with *Artemis salina*. The lowest food consumption, in wet weight and in energy was observed in those fed with *Themisto gracilipes* which showed the lowest growth. On the other hand, those fed with *Artemis salina* consumed the most food in wet weight, and grew very quickly. The food consumption of energy of those fed with fish silage was high, and the growth rate was between above two, but the conversion efficiency was too low. Moreover fish condition factors showed that the growth of the sandlance fed with *Artemis salina* was the most similar to that of nature. So if live sandlance nature food is inaccessible, *Artemis salina* can replace sandlance's nature food in lab.

Key words: food consumption; growth; conversion efficiency; feed; *Ammodyte personatus*

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