

四十里湾栉孔扇贝清滤率、摄食率和吸收效率的现场研究

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摘要:运用生物沉积法在四十里湾不同海区对栉孔扇贝的生理生态学特征进行了研究。1 龄栉孔扇贝(41.1±4.1mm, 软体干重 0.48±0.10g/ind)清滤率变化范围为 0.72~2.54 (平均 1.27) L/(ind·h)或 1.65~5.97(平均 2.61) L/(g·h)。清滤率受 TPM 的变化影响不大,而摄食率却随 TPM 的升高而升高。2 龄扇贝(软体干重 1.91±0.32g/ind)清滤率为 2.09~3.99(平均 3.10) L/(ind·h)。栉孔扇贝吸收速率与 POM 呈正相关关系,而与饵料质量 (POM/TPM)无明显的相关性。1 龄扇贝和 2 龄扇贝吸收效率没有显著差别;扇贝对 POM 的吸收效率与 TPM (或 POM)关系不大,却与饵料质量呈明显的正相关关系;扇贝对 POC、PON 和 PP 的吸收效率平均分别为 68.9%、64.0%和 63.6%。在沿岸养殖海域,栉孔扇贝通过大量的滤水摄食以及较高的吸收效率对生态系统的能量流动和物质循环产生影响。

关键词:四十里湾;生物沉积法;栉孔扇贝;清滤率;摄食率;吸收效率

Clearance Rate, Ingestion Rate and Absorption Efficiency of the Scallop *Chlamys farreri* Measured by *in situ* Biodeposition Method

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Abstract: The scallop *Chlamys farreri* Jones and Preston is one of the major bivalve species maricultured in China. The intensive aquaculture of this species in recent years has led to depressed growth rate and increased mortality. In order to estimate the carrying capacity for scallop culture in the sea, it is necessary to determine accurately the feeding rate and absorption rate and efficiency by the scallop. Studies on *in situ* biodeposition by *C. farreri* using PVC cylinders in 8 suspended farming zones in Sishili Bay with a total area of 13,000 hm² on the northern Yellow Sea coast were carried out in the summer (June to July) of 1998 in order to determine its eco-physiological parameters, including clearance rate (CR), ingestion rate (IR) and absorption efficiency (AE). In one cylinder was hanged a 20 mm mesh net at 30 mm from the top of the cylinder to contain 18 evenly-placed one-year-old scallops, and in another cylinder at 50 mm from the top of the cylinder to contain 9 two-year-old scallops; The control cylinder contained no scallops. The density and size of experimental scallops corresponded with those of the field cultivated scallops in Sishili Bay. The top of each cylinder was covered by a 20 mm mesh net. All sediment traps were suspended directly under raft line so that the experimental scallops were at water depth of about 2 m. During the experiment, the surface water temperature was 17.8~20.9°C, and seawater salinity changed slightly from 30.15 to 30.65. The concentrations of total suspended particulate matter (TPM) at different stations ranged from 1.46 to 5.03

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mg/L. *CR* of one-year-old scallops (shell height, 41.1 ± 4.1 mm; soft tissue dry weight, 0.48 ± 0.10 g/ind) had *CR* ranging from 0.72 to 2.54 (mean 1.27) L/(ind · h). *CR* was slightly affected by change in *TPM*, while *IR* was positively correlated to *TPM*. For two-year-old scallops with soft tissue dry weight of 1.91 ± 0.32 g/ind, *CR* ranged from 2.09 to 3.99 (mean 2.61) L/(ind · h). The absorption rate (*AR*) of one-year old scallops had positive correlation with *POM* (or *TPM*), but not with food quality (ratio of *POM/TPM*). There were no significant differences between *AE* of the one-year-old scallops and that of the two-year-old scallops. *AE* of *POM* was poorly correlated with *TPM* (or *POM*), but positively correlated with food quality. Mean *AE* of *POC*, *PON* and *PP* were 68.9%, 64.0% and 63.6%, respectively. In coastal intensive raft-culture areas, scallops may have great impact on energy flow and material cycling of the ecosystem by filtration and absorption of particulate suspended matter.

Key words: Sishili Bay; *in situ* biodeposition method; *Chlamys farreri*; clearance rate; ingestion rate; absorption efficiency

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滤食性双壳贝类通过大量的滤水、摄食、吸收、排泄、排粪和生长等生理活动,在沿岸能量生态学和营养动力学中扮演着重要角色。清滤率(clearance rate; *CR*)作为贝类摄食活动的一个重要指标被定义为单位时间内悬浮颗粒物被滤除掉那部分水的体积^[1];通常存在两种测定方法:一是静水系统法,亦称为 Coughlan 方法;二是流水系统法^[2]。以上两种方法均涉及到测量贝类对水中悬浮颗粒物的去除。清滤率与总悬浮颗粒物浓度(*TPM*)的乘积即为贝类的滤食率(filtration rate; *FR*)。在不产生假粪时,通常将滤食率视为摄食率(ingestion rate; *IR*)。然而,简单的静水和流水箱法排除了自然条件下海水流速的可变性。而流速能够影响双壳贝类的摄食和生长^[3]。沿岸潮流和风的变化能引起海水悬浮物数量和质量短期内的变化,因而也影响贝类的摄食活动^[4]。贝类吸收效率(absorption efficiency; *AE*)是贝类能量研究中重要的基本参数之一^[5]。贝类吸收效率的传统测定方法,即由 Conover 1966a 提出的比率法^[6],基于食物和粪便中的有机质含量(灰化法测定)。近几年来,越来越多研究者应用生物沉积法(biodeposition method)进行贝类生理生态学参数的测定,这些参数包括清滤率、摄食率、吸收效率和生长余力^[7~10]。生物沉积法原理:假定贝类不吸收饵料中的无机物,即用粪中灰分含量作为贝类所过滤物质的示踪物。Iglesias 等 1998 年对生物沉积法进行了积极性的评论^[9]。与传统测定方法(随机取样或间断式取样)相比,生物沉积法的主要改进在于:在自然颗粒物供给和水流条件下进行双壳贝类生理生态学参数的测定,具有完整的长时间尺度性,因而受贝类偶然摄食行为的变化影响很小;能够提供摄食的连续记录,因而更能精确地测量双壳贝类的摄食与吸收,这有助于准确地评价双壳贝类在沿海生态系统能量流动和物质循环中所起的作用。

我国栉孔扇贝 *Chlamys farreri* Jones & Preston 的浅海筏式养殖其规模和数量在世界上是无可匹敌的,在我国的海水养殖产业中也占据着相当重要的地位。然而近几年来,我国的栉孔扇贝养殖出现大规模死亡现象,损失惨重。已有共识,扇贝的死亡与过度开发有关。本文运用生物沉积法在四十里湾养殖海区现场对栉孔扇贝的清滤率、摄食率和吸收效率进行了测定,旨在为可持续发展的扇贝养殖提供基础数据。

2 材料与方法

2.1 站位设置及实验方法 本研究于 1998a 夏季(6~7 月份)于烟台四十里湾贝类养殖海区进行。共设 8 个站位(图 1、表 1)。沉积物捕集器如图 2 所示。在距 PVC 圆桶口部及离口部 3cm (1 龄扇贝)或 5cm (2 龄扇贝)的地方各放置一层孔径约 1cm 的尼龙网片。实验之前,首先使扇贝(事先已除去贝壳上肉眼能观察到的污损生物)均匀地固着在第 2 层丝网上,方法是将固着栉孔扇贝的具孔橡胶盘片小心地沿着栉孔扇贝周围剪切,将固着栉孔扇贝的橡胶碎片固定在网片上。PVC 桶中所实验 1 龄栉孔扇贝数目为 18 个,2 龄为 9 个。各站均设不放扇贝的圆桶作对照(丝网上只放适量的贝壳和橡胶碎片)。将圆桶固定在空旷的筏架上(周围 20m 内无养殖扇贝)圆桶口部离水面约 2m。实验设 3 个重复。

于实验起始和结束时取水样,测定海水中的总悬浮颗粒物浓度(*TPM*)、颗粒有机质浓度(*POM*)、颗粒

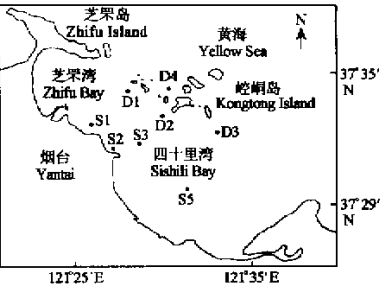


图1 研究海域(四十里湾)站位设置

Fig. 1 Location of stations for studies of *in situ* biodeposition by scallops in Sishili Bay

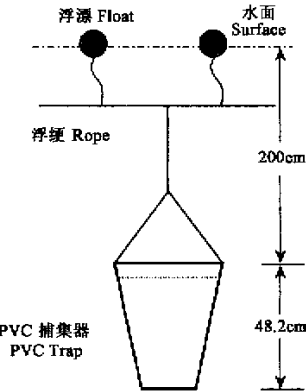


图2 扇贝生物沉积物捕集器

Fig. 2 Trap for collection of biodeposits produced by scallops

PVC 捕集器口部直径为 40.9cm,底部直径为 32.8cm
The ID of top and bottom of the PVC trap are 40.9cm and 32.8cm respectively

表1 站位设置及实验时间

Table 1 Stations and experiment date

站位 Station	水深(m) Depth	实验时间 Survey date
坦岛养殖海区(D1)	12	7.03~7.10
崆峒岛西南部养殖海区(D2)	9	7.10~7.15
崆峒岛东南部养殖海区(D3)	14	7.04~7.16
崆峒岛西北部养殖海区(D4)	16	7.10~7.15
月亮湾养殖海区(S1)	7	6.14~6.25
海水浴场养殖海区(S2)	5	6.18~6.26
金沟湾养殖海区(S3)	8	6.19~6.28
四十里湾养殖海区(S5)	12	7.04~7.17

D1 Dandao culture area; D2, Southwest Kongtongdao culture area;D3, Southeast Kongtongdao culture area;D4, Northwest Kongtongdao culture area;S1, Moon Bay culture area;S2, Bathingbeach culture area;S3, Jingou Bay culture area;S5, Sishili Bay culture area

有机碳(POC)、颗粒有机氮(PON)和颗粒总磷(PP)。用事先于 500 C 灼烧 3hr 并称重的 GF/C 滤膜(直径 4.7cm)过滤 1~3 L 水样,若分析 TPM,则用蒸馏水脱盐。滤膜于 70 C 干燥 24h,称重以测定 TPM。POM,即不含灰干重,用传统的灰化前后重量差法测定。PP 用经改进的 Solórzano & Sharp 法测定,即用 MgCl₂ 代替 MgSO₄ 作为灰化助剂^[11,12]。海水中的 POC 和 PON 用 Perkin-Elmer (240C 型)CHN 元素分析仪测定,分析前将滤膜放在干燥器中用 HCl 烟雾去除碳酸盐^[13]。另外,还测定海水水温、pH、盐度、溶解氧。沉积物捕集器在海水中放置一定时间后,取出并带回实验室,取出扇贝,静置 5h,让水中的悬浮颗粒物充分沉淀下来,虹吸出多余的海水,收集沉积物,用蒸馏水冲洗去盐后烘干(60 C,4d)。沉积物中的有机质(OM)、有机碳(OC)、有机氮(ON)、无机磷(IP)、有机磷(OP)和总磷(TP)的分析方法与上述颗粒物的分析方法类似。对各个捕集器的扇贝,分别测量壳高及软体干重(60 C,4d)。在本研

究中,扇贝的生物沉积速率通过扇贝捕集器与对照捕集器所收集沉积物的差值来估算。

2.2 实验扇贝的规格

实验用的栉孔扇贝均取自各养殖海区^[14]。所用 1 龄栉孔扇贝平均壳高为 41.1mm(SD=4.1mm);2 龄栉孔扇贝平均壳高为 60.9(SD=8.2)mm。1 龄栉孔扇贝总干重为 4.45±0.37g/ind,软体干重为 0.54±0.03g/ind;2 龄扇贝干重为 14.1±2.89g/ind,软体干重为 1.91±0.32g/ind。

2.3 参数的计算方法

根据生物沉积法测定滤食性动物清滤率:
 $IFR=IBD;CR=IFR/PIM=IBD/PIM;FR=CR\cdot TPM=IBD\cdot TPM/PIM;OFR=IBD\cdot r$
其中,IFR、IBD 为贝类对无机物的过滤速率(inorganic matter filtration rate)和生物沉积速率(inorganic matter biodeposition rate);PIM 为海水中颗粒无机物浓度(particulate inorganic matter);TPM 为总颗粒物浓度(total particulate matter);r 为 POM(或 POC、PON、PP)与 PIM 的比值;与 r 比值相对应,

OFR 为贝类对 *POM*(或 *POC*、*PON*、*PP*)的有机滤食速率。

由于四十里湾海区 6、7 月份饵料浓度不高,假粪产生很少,可以忽略不计^[15],因而以上所得到的贝类滤食率可被视为贝类的摄食速率。一般认为滤食性贝类假粪产生的数量相对大小与饵料浓度有关,如在 *Lynther* 河口湾 1g 重的贻贝产生假粪的阈值为 5mg/L^[16]。而 *Kuang* 等^[17]在中国桑沟湾观察到海水中的 *TPM* 在 5 月份达 17.7mg/L,但栉孔扇贝仍仅产生很少量的假粪。另外,巨扇贝 *Placocoecten magellanicus* 在自然悬浮物浓度高达 10mg/L 时并不产生假粪^[18]。

生物沉积法测定贝类吸收效率:
 $AR = OFR - OBD = IBD \cdot r - OBD$; $AE = AR / OIR = AR / OFR = AR / (IBD \cdot r) \times 100$ 或 $AE = AR / OFR = (1 - OBD / IBD \cdot r) \times 100$

AR 为扇贝对有机质的吸收速率(absorption rate);*OIR* 为贝类对有机物的摄食速率;与 *r* 比值相对应,*OBD* 为贝类对 *POM*(或 *POC*、*PON* 和 *PP*)的生物沉积速率。

从以上表达式可以看出,吸收速率(*AR*)的测定并不需要分别估计粪和假粪中有机物的排出量,而只需测定生物沉积物的总有机排出速率(*OBD*)即可。根据清滤率、滤食率的计算公式可知,沉积物有机质是否矿化并不影响这些指标的测定,但却影响吸收速率和吸收效率的测定。

3 结果

3.1 海区的水质特征

实验期间整个四十里湾海区的盐度的变化很小,30.15~30.65;表层水 pH 变化范围为 7.86~8.36;表层水溶解氧范围为 5.06~6.07 ml/L,饱和度为 95%~110%;表层水温变化范围为 17.8~20.9℃,底层水温为 14.1~17.6℃。表 3 列出了四十里湾养殖海区海水的颗粒物特征。整个海区饵料浓度变化较大,总悬浮颗粒物(*TPM*)浓度范围为 1.46~5.03 (平均 2.91,*SD*=1.29) mg/L。比较而言,S2 站水浅,可能受潮流等的影响较大,*TPM* 较高,而 *POM/TPM* 值较低;担蛋-崆峒岛一带海区 *TPM* 较低。*POM*、*POC*、*PON* 和 *PP* 含量在 S1 站最高。

表 3 四十里湾养殖海区海水悬浮物及其化学组成

Table 3 Suspended particulate matter and their chemical composition in raft culture areas in Sishili Bay									
站位 Station	<i>TPM</i> (mg/L)	<i>POM</i> (mg/L)	<i>POM/TPM</i> (%)	<i>POC</i> (mg/L)	<i>PON</i> (μg/L)	<i>PP</i> (μg/L)	C/N	N/P	C/P
D1	1.69±0.38	0.68	59.2	0.25	33.0	7.4	8.8	9.9	87.4
D2	2.00±0.49	0.85	59.5	0.33	33.5	9.5	11.5	7.8	90.1
D3	1.46±0.43	0.51	51.4	0.19	24.1	4.9	9.2	10.9	100.5
D4	2.26±0.68	0.79	46.5	0.28	31.3	6.6	10.4	10.6	110.2
S1	4.15±1.05	1.85	49.4	0.75	97.0	18.8	9.0	11.4	103.1
S2	5.03±1.24	1.63	30.6	0.65	66.6	16.0	11.4	9.2	105.2
S3	3.57±0.91	1.43	41.3	0.57	61.7	14.0	10.8	9.8	105.5
S5	3.11±0.87	1.15	41.2	0.40	40.7	10.1	11.5	8.9	102.0
平均	2.91	1.11	47.4	0.43	48.5	10.9	10.3	9.8	100.5
<i>SD</i>	1.29	0.45	9.1	0.19	23.1	4.6	1.1	1.1	7.34

3.2 清滤率、摄食率

栉孔扇贝清滤率(*CR*)的测定结果见表 4。不同海区扇贝的清滤率有变化,整个四十里湾海区 1 龄栉孔扇贝清滤率在夏季的变化范围为 0.72~2.54 L/(ind·h),平均 1.27(*SD*=0.51) L/(ind·h);清滤率与总悬浮颗粒物(*TPM*)或饵料质量(*POM/TPM*)没有明显关系。比较而言,2 龄栉孔扇贝的清滤率为 2.09~3.99 L/(ind·h),平均为 3.10(*SD*=0.78) L/(ind·h),高于 1 龄栉孔扇贝。但对单位软体干重而言,2 龄扇贝的清滤率为 1.62±0.51 L/(g·h),明显低于 1 龄扇贝的清滤率。表 4 还列出了不同海区扇贝对颗粒有机质(*POM*)或数据 *PON* 和 *PP* 的摄食率。1 龄扇贝的总摄食速率为 1.22~5.73(平均 3.56,*SD*=1.48)mg/(ind·h)。2 龄扇贝总的摄食率平均为 6.99(*SD*=1.51)mg/(ind·h),高于 1 龄扇贝,而以单位

软体干重(g)表示,则摄食率为 $3.51 \pm 0.57 \text{mg}/(\text{g} \cdot \text{h})$,却明显低于 1 龄扇贝。摄食率(FR)与 TPM (或 POM)呈正相关关系($FR=1.147 TPM, R_2=0.412$)而与饵料质量无显著关系。

表 4 四十里湾 1 龄栉孔扇贝清滤率、摄食率和吸收效率的现场测定结果

Table 4 *Chlamys farreri*. Clearance rate, ingestion rate and absorption efficiency of one-year-old scallop individuals in Sishili Bay

站位	CR	FR	FR _{POM}	FR _{POC}	FR _{PON}	FR _{PP}	AR _{POM}	AR _{POC}	AR _{PON}	AR _{PP}	AE _{POM}	AE _{POC}	AE _{PON}	AE _{PP}
Station	L/(ind·h)	mg/(ind·h)	μg/(ind·h)				mg/(ind·h)	μg/(ind·h)		(%)				
1 龄栉孔扇贝 One-year old scallop														
D1	0.72	1.22	0.49	0.180	23.8	5.3	0.344	0.110	13.6	3.14	70.2	61.1	57.3	59.1
D2	1.11	2.22	0.94	0.367	37.3	10.5	0.769	0.291	27.6	8.31	81.4	79.3	74.1	79.0
D3	1.35	1.97	0.69	0.256	32.4	6.6	0.490	0.185	21.0	3.42	71.3	72.2	64.8	52.1
D4	2.54	5.73	2.00	0.710	79.5	16.7	1.641	0.544	53.9	11.30	81.9	76.6	67.8	67.8
S1	1.15	4.76	2.12	0.860	111.2	21.6	1.754	0.694	92.0	17.53	82.7	80.7	82.7	81.3
S2	0.92	4.61	1.49	0.596	61.1	14.6	0.819	0.319	27.6	8.49	54.8	53.5	45.3	58.0
S3	1.20	4.28	1.71	0.683	74.0	16.7	1.232	0.462	48.1	8.68	72.1	67.6	65.0	51.9
S5	1.18	3.68	1.36	0.473	48.1	12.0	1.006	0.286	26.6	7.11	74.0	60.5	55.2	59.4
平均	1.27	3.56	1.35	0.516	58.4	13.0	1.007	0.361	38.8	8.50	73.6	68.9	64.0	63.6
SD	0.51	1.48	0.56	0.222	27.2	5.1	0.476	0.181	23.7	4.27	8.6	9.2	10.8	10.7
2 龄栉孔扇贝 Two-year old scallop														
D1	3.21	5.42	2.18	0.80	105.9	23.7	1.72	0.629	80.6	17.7	78.8	78.5	76.1	74.9
D4	3.99	9.03	3.16	1.12	125.1	26.2	2.37	0.804	78.3	16.8	75.0	71.9	62.6	63.9
S5	2.09	6.51	2.41	0.84	85.2	21.2	1.75	0.548	53.1	12.2	72.8	65.5	62.4	57.7
平均	3.10	6.99	2.58	0.92	105.4	23.7	1.95	0.660	70.68	15.58	75.5	71.9	67.0	65.5
SD	0.78	1.51	0.42	0.14	16.3	2.1	0.30	0.107	12.45	2.40	2.5	5.3	6.4	7.1

CR 为清滤率;FR 为滤食率;FR_{POC}、AR_{POC}、AE_{POC} 分别表示对颗粒有机碳(POC)的摄食率、吸收速率和吸收效率。CR, clearance rate;FR, filtration rate; FR_{POC}、AR_{POC}、AE_{POC}: POC filtration rate, absorption rate and absorption efficiency

3.3 吸收速率与吸收效率

1 龄扇贝对 POM 、 POC 、 PON 和 PP 的吸收速率(AR)分别为 $1.007 (SD=0.476)$ 、 $0.361 (SD=0.181)$ 、 $0.0388 (SD=0.0237)$ 和 $0.00850 (SD=0.00427) \text{mg}/(\text{ind} \cdot \text{h})$ (表 4); AR 与 POM (或 TDM)呈正相关关系,但与 POM/TPM 比值无明显的相关关系。1 龄扇贝对 POM 、 POC 、 PON 和 PP 的吸收效率分别为 $73.6 (SD=8.6) \%$ 、 $68.9 (SD=9.2) \%$ 、 $64.0 (SD=10.8) \%$ 和 $63.6 (SD=10.7) \%$;吸收效率(AE_{POM})与 TPM (或 POM)没有明显的相关关系,而与饵料质量(POM/PTM)却比较明显的呈正相关关系:

$$\ln(AE_{POM}) = 0.801\ln(POM/TPM) + 1.410 \quad (R^2=0.51)$$

2 龄扇贝对 POM 、 POC 、 PON 和 PP 吸收(效)率分别为 $75.5 \%(SD=2.5 \%)$ 、 $71.9 \%(SD=5.3 \%)$ 、 $67.0 \%(SD=6.4 \%)$ 和 $65.5 \%(SD=7.1 \%)$ 。不同海区栉孔扇贝 AE_{POM} 、 AE_{POC} 、 AE_{PON} 和 AE_{PP} 没有显著变化,与扇贝大小也没有明显关系。比较而言扇贝对 PON 的吸收效率略高于对 PP 的吸收效率。

4 讨论

沉积物捕集器被广泛地应用于测量海洋和沿岸环境中水柱的颗粒物通量。目前,捕集器内是否放置毒物或防腐剂尚存分歧。但目前一般认为,在捕集器短期放置内(如一星期以内),不加防腐剂时因微生物降解而造成测量的偏差低于加防腐剂时因浮游生物污染而产生的偏差^[19]。

在本研究中不同站位海水温度和盐度差别很小,它们不是栉孔扇贝生理生态参数差异的主要因子。本文应用生物沉积法的测定结果表明,栉孔扇贝的清滤率与 POM (或 TPM)没有明显关系。Kuang 等在桑沟湾现场用传统流水系统法以 $Chl-a$ 作为饵料指标测定了栉孔扇贝的清滤率^[17],他们也指出扇贝清滤率与饵料浓度和饵料质量的关系不明显;根据他们给出的 5 月份栉孔扇贝清滤率与软体之间关系式计算软体干重为 0.48g 扇贝的清滤率为 $2.83 \text{L}/\text{h}$,这高于本文结果。这可能主要与测定方法(本文以 POM 为饵料指

标)、海水温度、饵料浓度等因素有关。孙慧玲等同时用 *POM* 和 *Chl-a* 测定栉孔扇贝的清滤率,观察到两种测定方法的结果有一定的差异^[20]。已有研究证明,贝类的清滤率的影响因素包括温度^[17]、盐度^[21]、饵料浓度和质量^[5,22]、颗粒物体积^[23]以及其它环境因子。但 *Logy* 海湾马貽贝 *Modiolus modiolus* 的清滤率与饵料和温度等因子都无关^[2]。相似的结果还包括纽芬兰的紫貽贝 *Mytilus edulis* 和英格兰的食用鸟蛤 *Cerastoderma edule*^[24]。另外,底上动物巨扇贝 *Placopecten magellanicus* 和底内动物软壳蛤(砂海螂) *Mya arenaria* 的清滤率随悬浮颗粒物数量和有机物含量的增加而降低^[25];而食用鸟蛤 *C. edule* 的清滤率与悬浮物浓度呈明显的负相关关系^[26]。四十里湾栉孔扇贝的摄食率随饵料浓度的升高而升高,但饵料质量 (*POM/TPM*) 对摄食率没有显著影响;这与貽贝 *Mytilus galloprovincialis*^[7] 和 *M. edulis*^[27] 一致。Navarro & Widdows 报道 *C. edule* 的摄食率与悬浮物浓度也呈正相关关系,但当悬浮物超过 3mg/L 时,摄食率骤然下降^[26]。

关于栉孔扇贝的吸收效率(国内经常视之为“同化率”)已有不少报道^[17,28,29]。他们的测定方法均采用由 Conover 1966 年提出的传统比率法^[6]。Kuang 等用现场流水系统法测定了桑沟湾栉孔扇贝在 5 月份的吸收效率约为 60%^[17]。毛兴华等在实验室内分别用金藻(有机质含量为 91.6%,浓度为 3.56mg/L)、海带(有机质含量为 45.5%,浓度为 7.00 mg/L)和底泥(有机质含量为 27.3%,浓度为 7.00mg/L)作饵料测得栉孔扇贝的吸收效率分别为 91.6%、45.5%和 43.1%^[28]。张涛等用传统的方法测定了烟台四十里湾养殖海区栉孔扇贝的吸收效率,在夏季(6~8 月份)的变化范围约为 30%~60%,平均为 46.5%^[29];这明显低于本文用生物沉积法测定的结果。有关其它双壳贝类在自然海区较高的吸收效率也有很多报道,如巨扇贝 *P. magellanicus*^[8]、马貽贝(即偏顶蛤) *M. modiolus*^[2]等在自然海区中的吸收效率达 80%,甚至高至 90%。这与低水平饵料浓度有关^[2]。当食物供给降低时,双壳贝类具有提高吸收效率的能力^[16]。一些动物能够增加食物在胃的保留时间以补偿食物供给的不足^[30]。与其他双壳贝类一致^[2],栉孔扇贝的个体大小对吸收效率也没有显著的影响。Navarro & Thompson 认为这很可能由于控制吸收效率的生理因素(如纤毛和酶的活性等)不依赖于个体大小^[2]。

四十里湾不同养殖海区饵料浓度有不小的变化,然而栉孔扇贝对悬浮颗粒有机物的吸收效率却变化甚小。这说明 *TPM* 或 *POM* 在一定范围内对扇贝吸收效率的影响不大。已有研究证明硬壳蛤 *Mercenaria mercenaria*、巨扇贝 *P. magellanicus*、食用鸟蛤 *C. edule* 和紫貽贝 *M. edulis* 的吸收效率与 *TPM* 或 *POM* 没有显著关系^[27,31,32]。而马貽贝 *M. modiolus* 在 *Logy* 湾的吸收效率与任何环境因子都无显著关系^[2]。巨扇贝 *P. magellanicus* 吸收效率变化的 74%~84%归因于饵料质量的变化,而受饵料数量的影响不显著^[32]。Kuang 等也观察到桑海湾栉孔扇贝吸收效率与 *TPM* 的关系不密切^[17]。尽管栉孔扇贝吸收效率与饵料浓度关系不大,然而却与饵料质量关系密切,两者呈正相关关系。MacDonald 等也观察到底内动物软壳蛤 *M. arenaria* 和底上动物巨扇贝 *P. magellanicus* 的吸收效率随饵料质量的增高而升高^[31]。类似的报道还包括硬壳蛤 *M. mercenaria*、紫貽贝 *M. edulis* 和食用鸟蛤 *C. edule*,这些贝类的吸收效率均随饵料质量的升高而升高,且不依赖于饵料浓度^[27]。栉孔扇贝 N 的吸收效率略高于 C 和 P 的吸收效率,这与其它贝类一致^[33];这说明扇贝更趋向于对 N 的富集。

四十里湾是我国北方重要养殖海区之一^[34],其总面积约 13 000 hm²,平均水深约 10m;贝类养殖面积约 19350“亩”(在我国传统的养殖模式中,以 400 笼扇贝所占的水面作为一“亩”),每“亩”养殖数量约 140 000 粒。以本文 1 龄和 2 龄栉孔扇贝清滤率的平均值(2.2 L/(ind·h))计算,四十里湾所养殖的扇贝大约只需 9d 即可过滤整个湾内的海水。在沿岸养殖海域,栉孔扇贝可能通过快速的滤水、摄食以及较高的吸收效率对生态系统的能量流动和物质循环产生影响。

参考文献

- [1] Bayne, B L and Scullard C. Rates of nitrogen excretion by species of *Mytilus edulis* L. (Bivalvia Mollusca). *J. Mar. Biol. Assoc. U.K.*, 1977, **57**: 355~369.
- [2] Navarro J M and Thompson R J. Comparison and evaluation of different techniques for measuring absorption

- efficiency in suspension feeders. *Limnol. Oceanogr.*, 1996, **39**: 159~164.
- [3] Pilditch C A and Grant J. Effect of variations in flow velocity and phytoplankton concentration on sea scallop (*Placopecten magellanicus*) grazing rates. *J. Exp. Mar. Biol. Ecol.*, 1999, **240**: 111~136.
- [4] Fegley S R, MacDonald B A and Jacobsen T R. Short-term variation in the quantity and quality of seston available to benthic suspension feeders. *Estuarine Coastal Shelf Sci.*, 1992, **34**: 393~412.
- [5] Riisgard H U. Filtration rate and growth in the blue mussel, *Mytilus edulis* Linnaeus, 1758: dependence on algal concentration. *J. Shellfish Res.*, 1991, **10**: 29~35.
- [6] Conover R J. Assimilation of organic matter by zooplankton. *Limnol. Oceanogr.* 1966, **11**: 338~345.
- [7] Navarro E, Iglesias J I P, Camacho A P, *et al.* The physiological energetics of mussels (*Mytilus galloprovincialis*) from different cultivation rafts in the Ria de Arosa (Galicia, N. W. Spain). *Aquaculture*, 1991, **94**: 197~212.
- [8] Cranford P and Hargrave B T. *In situ* time-series measurement of ingestion and absorption rates of suspension-feeding bivalves: *Placopecten magellanicus*. *Limnol. Oceanogr.*, 1994, **39**: 730~738.
- [9] Iglesias J I P, Urrutia M B, Navarro E, *et al.* Measuring feeding and absorption in suspension-feeding bivalves: an appraisal of the biodeposition method. *J. Exp. Mar. Biol. Ecol.*, 1998, **219**: 71~86.
- [10] Bayne B L, Hedgecock D, McGoldrick D, *et al.* Feeding behaviour and metabolic efficiency contribute to growth heterosis in Pacific Oysters [*Crassostrea gigas* (Thunberg)]. *J. Exp. Mar. Biol. Ecol.*, 1999, **233**: 115~130.
- [11] Zhou Y (周毅), Zhang F S (张福绥), Yang H S (杨红生), *et al.* A comparison of efficacy of different ashing auxiliaries used in the phosphorus determination by ignition method. *Chinese Journal of Analysis Laboratory* (in Chinese)(分析试验室), 2001, **20**(6): 58~61.
- [12] Zhou Y (周毅), Zhang F S (张福绥), Ma X N (马锡年), *et al.* A comparison of efficiency of different auxiliaries used in phosphorus determination by ignition method with $\text{Na}_4\text{P}_2\text{O}_7$ as standard phosphorus. *Acta Oceanologia Sinica*(in Chinese) (海洋学报), 2001, **23**(5): 98~104.
- [13] Grasshoff K, Erhardt M and Kremling K. *Methods of seawater analysis*. Weinheim: Verlag Chemie Press, 1983.
- [14] Zhou Y (周毅), Yang H S (杨红生), Zhang F S (张福绥). Scope for growth and C, N, and P budgets of the scallop *Chlamys* (*Azumapecten*) *farreri* measured by *in situ* biodeposition method. *Journal of Fishery Science of China*(in Chinese) (中国水产科学), 2002, **9**(2): 161~166.
- [15] Zhou Y (周毅), Yang H S (杨红生), Zhang F S (张福绥), *et al.* A study of biodeposition by *Chlamys farreri* in culture sea of Sishiliwan Bay. *Transactions of the Chinese society of malacology*(in Chinese) (贝类学论文集), No. 9. Beijing: Oceanography Press, 2001. 99~111.
- [16] Widdows J, Worrall C, Fieth P, *et al.* Relationship between seston, available food and feeding activity in the common mussel *Mytilus edulis*. *Mar. Biol.*, 1979, **50**: 195~207.
- [17] Kuang S, Fang J, Sun H, *et al.* Seasonal studies of filtration rate and absorption efficiency in the scallop *Chlamys farreri*. *J. Shellfish Res.*, 1997, **16**: 39~45.
- [18] MacDonald B A and Thompson R J. Influence of temperature and food availability on the ecological energetics of the giant scallop *Placopecten magellanicus*. III. Physiological ecology, the gametogenetic cycle and scope for growth. *Mar. Biol.*, 1986, **93**: 37~48.
- [19] Heiskanen A S. Contamination of sediment trap fluxes by vertically migrating phototrophic micro-organisms in the coastal Baltic Sea. *Mar. Ecol. Prog. Ser.*, 1995, **122**, 45~58.
- [20] Sun H L (孙慧玲), Fang J G (方建光), Kuang S H (匡世煊), *et al.* Filtration rate of scallop (*Chlamys chlamys*) cultured in simulated natural environment. *Journal of Fishery Science of China* (in Chinese)(中国水产科学), 1995, **27**(2): 194~199.
- [21] Navarro J M. The effect of salinity on physiological ecology of *Choromytilus chorus* (Molina, 1782) (Bivalvia: Mytilidae). *J. Exp. Mar. Biol. Ecol.*, 1988, **122**: 19~33.
- [22] MacDonald B A and Ward J E. Variation in food quality and particle selectivity in the sea scallop *Placopecten magellanicus* (Mollusca; Bivalvia). *Mar. Ecol. Prog. Ser.*, 1994, **108**: 251~264.

[23] Hawkins A J S, Fang J G, Pascoe P L, *et al.* Modelling short-term responsive adjustments in particle clearance rate among bivalve suspension-feeders; separate unimodal effects of seston volume and composition in the scallop *Chlamys chlamys*. *J. Exp. Mar. Biol. Ecol.*, 2001, **262**: 61~73.

[24] Newell R I E and Bayne B L. Seasonal changes in physiology, reproductive condition and carbohydrate content of the cockle *Cardium* (= *Cerastoderma*) *edule* (Bivalvia; Cardidae). *Mar. Biol.*, 1980, **56**: 11~19.

[25] Bacon G S, Bruce A, Macdonald B A, *et al.* Physiological responses of infaunal (*Mya arenaria*) and epifaunal (*Placopecten magellanicus*) bivalves to variations in the concentration of suspended particles I. Feeding activity and selection. *J. Exp. Mar. Biol. Ecol.*, 1998, **219**: 105~205.

[26] Navarro J M and Widdow J. Feeding physiology of *Cerastoderma edule* in response to a wide range of seston concentrations. *Mar. Ecol. Prog. Ser.*, 1997, **152**: 175~186.

[27] Bayne B L, Iglesias J I P, Hawkins A J S, *et al.* Feeding behaviour of the mussel *Mytilus edulis*; responses to variations in quantity and organic content of the seston. *J. Mar. Biol. Ass. U. K.*, 1993, **73**: 813~829.

[28] Mao X H (毛兴华), Hao Y W (郝亚威), Yang X L (杨小龙). Carbon and energy metabolism of the scallop *Argopecten irradians* and *Chlamys farreeri*. *Acta Oceanologia Sinica* (in Chinese) (海洋学报), 1997, **19**(4): 132~137.

[29] Zhang T (张涛), Yang H S (杨红生), Wang P (王萍), *et al.* Annual variation in absorption efficiency of *Chlamys farreri* in Sishili Bay, Yantai, and its relations to environment. *Oceanologia et Limnologia Sinica* (in Chinese) (海洋与湖沼), 2000, **31**(3): 266~272.

[30] Bayne B L and Newell R C. Physiological energetics of marine molluscs . In: Saleuddin A S M and Wilbur K M ed., *The Mollusca*. Vol. 4, Physiology, Part I. New York: Academic Press, 1984. 409.

[31] MacDonald B A, Bacon G S, Ward J W, *et al.* Physiological responses of infaunal (*Mya arenaria*) and epifaunal (*Placopecten magellanicus*) bivalves to variations in the concentration and suspended particles II. Absorption efficiency and scope for growth. *J. Exp. Mar. Biol. Ecol.*, 1998, **219**: 127~141.

[32] Cranford P J. Relationship between food quantity and quality and absorption efficiency in sea scallops *Placopecten magellanicus* (Gmelin). *J. Exp. Mar. Biol. Ecol.*, 1995, **189**: 124~142.

[33] Hawkins A J S and Bayne B L. Seasonal variation in the relative utilization of carbon and nitrogen by the mussel *Mytilus edulis*; budgets, conversion efficiencies and maintenance requirements. *Mar. Ecol. Prog. Ser.*, 1985, **25**: 181~188.

[34] Yang H, Zhang T, Wang J, *et al.* Growth characteristics of *Chlamys farreri* and its relation with environmental factors in intensive suspended-culture areas of Sishiliwan Bay, Yantai. *J. Shellfish Res.*, 1999, **18**: 71~76.