

应用 Ricker 动态综合模型模拟解析东海区伏季休渔效果

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摘要:中国政府于1995年正式宣布在东海区实施伏季休渔制度, 休渔范围为 $27^{\circ}00'N-35^{\circ}00'N$ 海域, 时间为每年的7月1日至8月31日; 1998年将范围进一步扩大到 $26^{\circ}00'N-35^{\circ}00'N$ 海域; 时间延长, 定为每年的6月16日至9月15日, 并在南海和渤海全面推广伏季休渔制度。自该制度的贯彻执行以来, 取得了显著的生态效益、经济效益和社会效益。本研究以东海区的主要经济鱼——带鱼(*Trichiurus japonicus*)为研究对象, 应用 Ricker 动态综合模型, 解析东海区实施3个月的伏季休渔效果, 揭示在不同的开捕年龄(t_c)与捕捞死亡系数(F)组合下对带鱼渔业资源保护和利用之间的规律。结果表明, 在目前开捕年龄偏低、网目尺寸偏小和捕捞压力较大的现实状况下, 东海区实施伏季休渔制度很有必要; 在带鱼开捕年龄为0.5龄、年捕捞死亡系数为1.5~3的渔业格局下, 实施3个月的伏季休渔制度后, 其年平均资源量、渔获量和渔获平均体重的增幅分别达到57.8%~104%、22.2%~32.2%和32.5%~42.9%, 但带鱼群体所提供的资源量水平、所获取的渔获量和渔获平均体重仍显偏低, 对其合理利用尚需要进一步完善; 若将开捕年龄从0.5龄提高至1龄, 则年平均资源量、渔获量和渔获平均体重的增幅分别达到173%~356%、72%~101%和149%~187%。鉴于东海区总体渔业资源状况呈衰退之势, 且中国尚未实施TAC渔业管理制度, 建议目前继续实施伏季休渔制度, 并把提高起捕规格、放大网目尺寸作为首选管理目标。[中国水产科学, 2006, 13(1): 85~91]

关键词: Ricker 动态综合模型; 伏季休渔; 开捕年龄; 渔业管理; 东海

中图分类号: S931 **文献标识码:** A **文章编号:** 1005-8737-(2006)01-0085-07

近20多年来, 海洋捕捞力量超速增长, 至20世纪90年代初期, 中国的东、黄海近海传统经济鱼类资源与20世纪70年代相比已发生了较大变化, 并呈现出严重衰退的局面。针对这些经济鱼类渔获个体日趋小型化、低龄化、性成熟提早的严峻生物学表现^[1], 中国政府于1995年正式宣布在东、黄海海域实施伏季休渔制度。东海区休渔范围为 $27^{\circ}00'N-35^{\circ}00'N$ 的东黄海海域, 时间为每年的7月1日至8月31日, 禁止拖网和帆式张网作业。经过3年实践, 1998年又在此基础上将范围进一步扩大到 $26^{\circ}00'N-35^{\circ}00'N$ 海域, 并将休渔时间延长, 定为每年的6月16日至9月15日, 且在此期间还陆续禁止定置网和拖虾网作业。该制度的贯彻执行, 取得了显著的生态效益、经济效益和社会效益, 且被广大渔民接受, 进而在中国的南海和渤海全面推广。

曾有学者从不同的角度对东海区伏季休渔效果进行了分析。程家骅等^[1]从渔业生态的角度分析

研究了伏季休渔效果; 徐汉祥等^[2]从带鱼(*Trichiurus japonicus*)生殖和补充特征研究了两者间的变动关系以及伏季休渔效果, 但上述研究主要是依赖于资源调查结果的分析, 而未从理论模型的角度进行多种渔业条件下的分析。在动态综合模型的应用方面, 由于Beverton-Holt模型估算资源种群所要求的各项结果是假设各时段相等, 且各时段的死亡系数(包括捕捞死亡系数和自然死亡系数)恒定, 并掌握其Von-Bertalanffy生长方程的各生长参数且匀速生长, 所以, 中国的许多学者普遍应用Beverton-Holt模型来分析研究在变更不同的开捕年龄与捕捞强度组合下对渔业资源利用的影响, 而Ricker模型则不要求各时段相等, 且各时段死亡系数可不相同, 也不一定需要Von-Bertalanffy生长方程的生长参数, 也不要求匀速生长的种群, 只需要各时段的始末体重资料和各时段不同的死亡系数, 在应用上该模型更贴近渔业实际(如考虑渔汛期、禁渔期)。詹秉义曾

收稿日期: 2005-02-02; 修订日期: 2005-04-30。

基金项目: 科技部公益性资助项目(东海区渔业资源动态监测网)。

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应用 Ricker 模型分析绿鳍马面鲀 (*Thamnaconus septentrionalis*)^[3] 和长江鲟鱼 (*Tenualosa reevesii*) 资源的合理利用^[4], Ricker 模型应用的经典例子是 Ricker (1958) 求算印第安那穆塞凯湖 (Muskellunge) 在 1 年中某一时间段为禁渔期的大鳍鱈太阳鱼 (*Lepomis macrochirus*) 单位补充量渔获量^[4]。因此, 本研究应用 Ricker 动态综合模型, 以东海区的主要经济鱼种——带鱼作为代表, 选取 3 个月的伏季休渔(禁渔期)作为分析期限, 在变更不同的渔业利用条件下, 考察其单位补充量年平均资源量、单位补充量年渔获量以及渔获质量的变化, 模拟解析伏季休渔效果; 同时, 针对当前的渔业利用现状, 分析了当前资源利用中存在的问题, 并提出操作性较强的渔业资源利用管理建议, 旨在为渔业资源研究与管理提供科学依据。

1 材料与方法

1.1 鱼种的选择依据及其参数值的确定

带鱼一直位居东海区海洋捕捞鱼类产量的首位^[5], 当初最先制定伏季休渔制度的目的主要就是为了保护与合理利用带鱼资源, 因此, 选择该鱼种来分析伏季休渔效果, 具有较好的代表性。

带鱼在东海区产卵期为 3~10 月, 从福建南部至江苏北部均有产卵, 南部早, 北部晚, 生长迅速^[6]。从大量的生物学测定结果表明, 一般带鱼缸长达 100~120 mm 的个体已被网具捕获, 由体长生长方程^[7]推算的年龄约为 0.25 龄, 说明带鱼出生后近 3 个月就成为补充群体进入渔场, 故带鱼的补充年龄 t_c 在本研究中取 0.25 龄。东海区带鱼的捕捞群体由 0~6 龄 7 个年龄组组成^[6], 本研究中最大年龄 t_d 取 6 龄。

带鱼的年自然死亡系数 M 为 0.44^[8]。带鱼的年捕捞死亡系数 F 在 20 世纪 70 年代后期为 2.09^[6], 此后捕捞力量的进一步超高速增长, 故本研究的带鱼 F 取值范围为 1.5~3。

1.2 动态综合模型的应用和计算方法

本研究应用 Ricker 动态综合模型, 将某一资源种群一个世代一生中的开发期分割为许多时段, 逐段对其资源量、渔获量和渔获尾数进行计算, 然后累加^[4]。

t 时间间隔中的平均资源量、渔获量和渔获尾数分别为:

$$\bar{B}_t = \frac{B_t [e^{(G_t - Z_t)} - 1]}{G_t - Z_t},$$

$$Y_t = F_t \bar{B}_t, C_t = \frac{F_t N_t}{Z_t} (1 - e^{-Z_t})$$

式中, B_t 为 t 龄时的资源量, 计算时以补充群体资源量的假设值 (B_c) 作为计算的起始值, 其后各龄的资源量 $B_{t+1} = B_t e^{(G_t - Z_t)}$; N_t 为 t 龄时的资源尾数, 其后各龄的资源尾数 $N_{t+1} = N_t e^{-Z_t}$; 体重相对增长率 (G_t) 计算公式为: $G_t = \ln W_{t+1} - \ln W_t$, 带鱼体重 (W_t) 的生长方程^[7]为 $W_t = 1.892 [1 - e^{-0.313(t+0.599)}]^{2.8802}$; Z_t 和 F_t 分别为 t 时间间隔内的总死亡系数和捕捞死亡系数。

至最大年龄 t_d 的单位补充量资源量 (\bar{B}/R)、单位补充量渔获量 (Y/R) 和平均渔获重量 (\bar{W}_y) 受人为捕捞活动作用的两个可控制变量即捕捞死亡系数 (F) 和开捕年龄 (t_c) 影响, 计算公式^[3]分别为:

$$\bar{B}/R = f_1(F, t_c) = \frac{\sum \bar{B}_t}{R},$$

$$Y/R = f_2(F, t_c) = \frac{\sum Y_t}{R},$$

$$\bar{W}_y = f_3(F, t_c) = \frac{\sum Y_t}{\sum C_t},$$

式中, R 为补充量, 计算式: $R = B_c / W_{t_c}$, W_{t_c} 为 t_c 时个体重量。

计算时, 只要设定不同的 F 和不同的 t_c 龄作为不同的 t_c , 就可方便地计算上述方程的解。

1.3 Ricker 动态综合模型的参数确定

1.3.1 生长年的选取 东海区带鱼的种群系东海群系, 其年轮形成时期为 12 月至翌年 4 月^[6], 该时期个体生长缓慢, 由于东海区纬度跨度大, 生长年不尽一致, 本研究取 3 月 15 日至 12 月 15 日为带鱼的生长年, 约 9 个月。

1.3.2 伏季休渔条件下各时间段的捕捞死亡系数 F 和自然死亡系数 M 的确定 东海区伏季休渔期为 6 月 16 日至 9 月 15 日, 其余时间均有作业。由于气候、渔获状况等因素, 在各时间段的捕捞努力量差异较大。据东海区 2001~2003 年拖网监测船的渔业统计记录^[1], 按带鱼渔汛期和兼捕期来确定利用带鱼的时间段为 9 月 16 日至 11 月 1 日, 11 月 1 日至 12 月 15 日, 12 月 15 日至翌年 3 月 15 日, 3 月

1) 东海区渔政港监督管理局. 东海区渔业资源动态监测网年会材料选编 [M]. 2001~2003.

15日至6月15日,总船数作业天数(以总作业船数 \times 作业天数为捕捞努力量单位)自9月16日至翌年6月15日的若干时间段依次占50%、20%、15%、15%。所以,捕捞死亡系数 F 在1年中的分布按上述比例分配到各时间段;在应用该模型时设自然死亡系数 M 在1年中的分布是相当均匀的^[4]。

1.3.3 开放捕鱼条件下各时间段的 F 和 M 确定

假设6月16日至9月15日开放捕鱼(不实施伏季休渔制度),在这种情况下,年捕捞死亡系数给予重新分配。东海区目前带鱼渔获量主要在秋季获取,冬季几乎形不成渔汛,开放捕鱼意味着提前对带鱼形成捕捞死亡,并使得全年的总捕捞死亡系数有所增加和不同时间段的捕捞死亡系数有所变化。由于在1个年份中开放捕鱼比实施伏季休渔的捕捞期增加了3个月,占到全年捕捞期的1/4,所以,开放捕鱼条件下的年捕捞死亡系数将比实施伏季休渔制度后增加25%,捕捞死亡系数在一年中的分配比例自6月16日至翌年6月15日的各时间段分别调整为40%、30%、10%、10%、10%。

2 结果

2.1 实施伏季休渔制度条件下的 \bar{B}/R 、 Y/R 和 \bar{W}_y 变化

根据 Ricker 动态综合模型,当 $t_c = 0.25$ 龄、 $t_h = 6$ 龄时,以不同的捕捞死亡系数 F 和开捕年龄 t_c 的取值组合,计算相应的 \bar{B}/R 、 Y/R 和 \bar{W}_y 。表1给出了 t_c 为0.5~2龄和 F 为1.5~3的模拟情况下,实施伏季休渔制度条件下的 \bar{B}/R 、 Y/R 和 \bar{W}_y 变化。

从带鱼所提供的 \bar{B}/R 来看,当 F 一定时, \bar{B}/R 是随着 t_c 的提高而显著上升;当 t_c 一定时, \bar{B}/R 是随着 F 增加而下降。因此,从保护渔业资源的角度考虑,应该降低捕捞强度,提高开捕年龄,从而达到恢复资源。

从带鱼所获取的 Y/R 来看,当 F 一定时, Y/R 是随着 t_c 的提高而上升;当 t_c 一定时, Y/R 是随着 F 增加而缓慢下降。因此,从渔业资源开发利用的角度来看,提高开捕年龄,更有利于渔获量的提高,而调整捕捞强度,其作用不甚明显。

从带鱼的 \bar{W}_y 来看,其变化规律与 \bar{B}/R 一致。因此,提高开捕年龄更有利于渔获质量的改善,而控制捕捞强度,其效果相对较小。

2.2 实施伏季休渔制度条件下和开放捕鱼条件下 \bar{B}/R 、 Y/R 和 \bar{W}_y 的差异

伏季休渔效果可从资源量和渔获量的增减以及渔获质量的变化3个指标最为直观地进行评价,所以,比较实施伏季休渔制度和开放捕鱼条件下 \bar{B}/R 、 Y/R 和 \bar{W}_y 的差异来分析伏季休渔效果,其对应的差异用相对值表示。表2列举了在 t_c 为0.5~2龄和 F 为1.5~3的模拟情况下,实施伏季休渔制度条件下的 \bar{B}/R 、 Y/R 和 \bar{W}_y 相对于开放捕鱼条件下的 \bar{B}/R 、 Y/R 和 \bar{W}_y 的同比增长率。

从 \bar{B}/R 的差异来看,实施伏季休渔制度条件下的 \bar{B}/R 均大于开放捕鱼条件下的 \bar{B}/R ,说明了实施伏季休渔制度对资源量均有增加的效果。当 t_c 为0.5龄时, \bar{B}/R 增长率随 F 的增加而明显增加;当 t_c 为1龄时, \bar{B}/R 增长率随 F 的增加而变化不大;当 t_c 为1.5~2龄时, \bar{B}/R 增长率随 F 的增加而下降。其总趋势是 t_c 越小, \bar{B}/R 增长率越大,并随着 F 的增加而递增。由此表明,开放捕鱼下的开捕规格越小和捕捞强度越高时,那么,实施伏季休渔制度越有利于带鱼资源的恢复。

从 Y/R 的差异来看, Y/R 增长率是随着 t_c 的提高而下降;当 t_c 一定时, Y/R 增长率是随着 F 的增加而递增,说明了开捕规格越小和捕捞强度越高,实施伏季休渔制度对带鱼渔获量的增加越明显。然而,当 t_c 达到2龄时, Y/R 增长率接近零或负值,说明了开放捕鱼和实施伏季休渔两种捕捞格局下的 Y/R 差异不大,体现在产量上已无实施伏季休渔制度的必要。

从 \bar{W}_y 的差异来看, \bar{W}_y 增长率与 \bar{B}/R 增长率变化趋势相同,说明了开放捕鱼条件下的捕捞强度越高和开捕规格越小时,那么,实施伏季休渔制度对带鱼渔获质量提高越明显(表2)。

3 讨论

3.1 实施伏季休渔制度对带鱼资源的增殖作用

从实施伏季休渔制度条件下和开放捕鱼条件下两种不同的捕捞格局下 \bar{B}/R 、 Y/R 和 \bar{W}_y 差异分析来看,当开放捕鱼条件下的捕捞强度越高和开捕规格越小时,实施伏季休渔制度后体现在资源量和渔获量的增长上以及渔获质量的提高上,效果越明显。但随着开捕年龄的提高,其效果越显削弱,而且随捕捞强度的变化影响不大。

表1 实施伏季休渔制度条件下变更开捕年龄和捕捞强度对带鱼渔业所产生的影响

Tab.1 Effects of changes in F and t_c on hairtail fishery during summer close

开捕年龄(t_c)/a Catchable age	指标 Index	年捕捞死亡系数(F) Fishing mortality coefficient			
		1.5	2.0	2.5	3.0
0.5	单位补充量资源量(\bar{B}/R)/g Biomass per recruitment	254	168	125	100
	单位补充量渔获量(Y/R)/g Yield per recruitment	78.2	69	63.2	59.5
	平均渔获重量(\bar{W}_y)/g Average body weight	102	86	76	70
1.0	单位补充量资源量(\bar{B}/R)/g Biomass per recruitment	693	571	501	456
	单位补充量渔获量(Y/R)/g Yield per recruitment	134.7	128.7	123.8	119.7
	平均渔获重量(\bar{W}_y)/g Average body weight	254	229	213	201
1.5	单位补充量资源量(\bar{B}/R)/g Biomass per recruitment	802	680	611	568
	单位补充量渔获量(Y/R)/g Yield per recruitment	147.1	144	141.6	139.9
	平均渔获重量(\bar{W}_y)/g Average body weight	299	278	265	257
2.0	单位补充量资源量(\bar{B}/R)/g Biomass per recruitment	1465	1333	1251	1196
	单位补充量渔获量(Y/R)/g Yield per recruitment	169.1	170.1	169.4	168.3
	平均渔获重量(\bar{W}_y)/g Average body weight	497	471	453	439

中国规定的拖网网囊的网目尺寸不小于54 mm^[8],由网目选择性推算的带鱼最小 t_c 为0.5龄^[9],那么,当 F 为1.5~3时,由开放捕鱼条件下到实施3个月的伏季休渔制度后,年平均资源量增幅为57.8%~104%,年渔获量增幅为22.2%~32.2%,渔获平均体重增幅为32.5%~42.9%(表2)。

在中国,目前实际生产中使用的网目尺寸或许更小,带鱼的 t_c 低于0.5龄,捕捞力量也处于超强的状态,由此可知,在目前 t_c 偏低、网目尺寸偏小和强大的捕捞压力下,实施伏季休渔制度是必要的。

3.2 伏季休渔管理措施的局限性

实施伏季休渔制度从渔业管理的本质上是降低捕捞强度,从实施伏季休渔制度条件下的 \bar{B}/R 、 Y/R 和 \bar{W}_y 分析结果来看,即使实施3个月的伏季休渔制度,由于开捕规格偏小,引起 \bar{B}/R 、 Y/R 和 \bar{W}_y

均偏低。然而,随着开捕规格的提高、网目尺寸的放大, \bar{B}/R 、 Y/R 和 \bar{W}_y 均随之增大(表1),说明中国虽实施了伏季休渔制度,但带鱼群体的利用结构仍然很不合理,带鱼群体所提供的资源量水平不高,所获取的渔获量偏低,渔获质量偏差,对带鱼资源的合理利用尚需要进一步的完善。

3.3 东海区带鱼资源的管理意见

从实施伏季休渔制度条件下的带鱼所提供的 \bar{B}/R 、 Y/R 和 \bar{W}_y 分析结果可知(表1),降低 F 虽有利于资源量的增加,但对渔获量的提高和渔获质量的改善所起的作用并不明显,更何况在现有的渔业情况下,大幅度的缩减捕捞强度是一件十分困难的工作。然而,提高 t_c 将会迅速提高 \bar{W}_y 、 Y/R 和 \bar{W}_y 的结果。所以,以提高起捕规格放大网目尺寸应作为首选的渔业管理目标。

表2 实施伏季休渔制度条件下的资源利用结果相对于开放捕鱼条件下的增长率

Tab.2 Increment rate of utilized results to fishery resources during summer close related to open free fishing

开捕年龄(t_c)/a Catchable age	增长率 Increment rate	年捕捞死亡系数(F) Fishing mortality coefficient			
		1.5	2.0	2.5	3.0
0.5	单位补充量资源量(\bar{B}/R)增长率 Increment rate of biomass per recruitment	57.8	69.7	86.6	104
	单位补充量渔获量(Y/R)增长率 Increment rate of yield per recruitment	22.2	25.5	29	32.2
	平均渔获重量(\bar{W}_y)增长率 Increment rate of average body weight	32.5	36.5	38.2	42.9
1.0	单位补充量资源量(\bar{B}/R)增长率 Increment rate of biomass per recruitment	34.3	35	34.7	34.1
	单位补充量渔获量(Y/R)增长率 Increment rate of yield per recruitment	9.5	10.9	12.6	12.9
	平均渔获重量(\bar{W}_y)增长率 Increment rate of average body weight	21	21.2	22.4	22.6
1.5	单位补充量资源量(\bar{B}/R)增长率 Increment rate of biomass per recruitment	13.1	10.2	5.34	4.22
	单位补充量渔获量(Y/R)增长率 Increment rate of yield per recruitment	2.2	2.5	2.6	2.9
	平均渔获重量(\bar{W}_y)增长率 Increment rate of average body weight	7.9	5.3	4.3	4.1
2.0	单位补充量资源量(\bar{B}/R)增长率 Increment rate of biomass per recruitment	12.7	12	11	10.1
	单位补充量渔获量(Y/R)增长率 Increment rate of yield per recruitment	-0.5	0.1	0.2	0.3
	平均渔获重量(\bar{W}_y)增长率 Increment rate of average body weight	5.7	5.6	5.5	5

从本研究结果可知,实施伏季休渔制度体现在资源量和渔获量的增加以及渔获质量的改善方面已初见成效。然而,无论是在开放捕鱼条件下还是在实施伏季休渔制度条件下,一旦提高 t_c 后,其效果更加显著。当 t_c 达到 2.0 龄时,体现在产量上已无实施伏季休渔制度的必要,说明提高 t_c 后对带鱼资源的保护和利用可达到更大的效果;且此时捕捞强度的变化对资源量和渔获质量的影响已不明显,这实际上从一个侧面佐证了提高开捕规格放大网目尺寸对渔业资源合理利用的重要性。

东、黄海海域为交叉型、复合性、多鱼种渔场,主要经济鱼种之间的索饵场、产卵场和越冬场不存在明显的地域差异,混栖现象十分明显,以致各种渔具

捕获的渔获物种类均较为多样化。目前包括带鱼在内的主要经济鱼种的渔获物几乎均以低龄鱼为主^[10],因此,适当提高开捕规格放大网目尺寸也有利于其他种类的合理利用。

据王明彦等^[9]研究表明,拖网网囊网目为 60 mm 比较适宜,其对应的带鱼首捕年龄在 0.9 龄以上;同时,东海带鱼的个体绝对生殖力随个体的增加而提高,性成熟比例随年龄的增长也明显上升,1 龄鱼性成熟比例达到 95%^[5,11]。综上所述并结合本研究结果,笔者认为,在实施伏季休渔制度的前提下,带鱼的 t_c 由 0.5 龄提高到 1 龄是比较合适的, \bar{B}/R 、 Y/R 和 \bar{W}_y 会明显提高,体现在资源量上将会增加 173%~356%,体现在渔获量上将会增加

72%~101%,体现在渔获平均体重上将增加149%~187%(表1),这些结果远高于仅实施3个月伏季休渔的效果。此外,提高开捕年龄后,随着个体绝对生殖力和性成熟比例的提高,可使带鱼的补充群体数量明显增加,有利于带鱼资源的恢复。

4 结语

本研究应用 Ricker 动态综合模型分析了不同渔业利用格局下对带鱼渔业所产生的影响,证实实施伏季休渔制度仅在开捕年龄偏低、网目尺寸偏小和强大的捕捞压力下才能体现出其效果,提高开捕年龄后伏季休渔的效果将会削弱,但 \bar{B}/R 、 Y/R 和 \bar{W} ,无论在实施伏季休渔制度条件下还是在开放捕鱼条件下却明显上升。通过本研究的实例解析,可见实施伏季休渔制度仅是当前渔业管理的权宜之计,是目前较为有效的渔业管理方案,而并非渔业管理的长期目标和可持续渔业管理目标。针对目前东海区总体渔业资源呈衰退之势且中国尚未实施 TAC 渔业管理的现实,建议在严格执行伏季休渔管理的同时,配合执行开捕规格的管理。这是目前合理利用东海区渔业资源较为科学和操作性强的渔业管理措施。

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Simulative analysis on results of summer closed fishing in the East China Sea with Ricker population dynamic pool model

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Abstract: The enforcement of the summer closed fishing in the East China Sea was declared by Chinese government in 1995 and the location for the closed fishing was $27^{\circ}00'N - 35^{\circ}00'N$ with the duration from July 1 to August 31 per year. In 1998 the location was extended to $26^{\circ}00'N - 35^{\circ}00'N$ and the duration was prolonged which was from June 16 to September 15 per year and the summer closed fishing area was extended to the South China Sea, the Yellow Sea and the Bohai Sea. The enforcement of the summer closed fishing has obtained obvious ecological, economical and social benefits and it is an important decision-making for sustainable fisheries development. In this paper the results of the three-month summer closed fishing (2001 – 2003) were analyzed by Ricker population dynamic pool model, based on a main commercial species-hairtail, *Thichiurus japonicus*, and revealed a rule between the conservation of hairtail stock and its utilization with combination of a different catchable age (t_c) and fishing mortality coefficient (F). The results indicated that it was necessary to carry out the summer closed fishing for the East China Sea under the case of a lower catchable age, a smaller mesh size and a larger fishing effort at present. If catchable age for hairtail was 0.5 year and annual fishing mortality coefficient was 1.5 – 3, its average annual biomass, catch and average individual body weight could be increased by 57% – 104%, 22.2% – 32.2% and 32.5% – 42.9%, respectively. However the biomass level, catch and average individual weight rooting in hairtail population was still lower and further reasonable utilization should be researched. If the catchable age is increased from 0.5 year to 1 year, the average annual biomass, catch and average individual weight will be increased by 173% – 356%, 72% – 101% and 149% – 187%, respectively. The fact is that the fishery resources are declining in the East China Sea and the TAC measure has not been enforced in China. We suggest the enforcement of summer closed fishing be continued, and catchable size and mesh size as the first management target be improved. [Journal of Fishery Sciences of China, 2006, 13(1): 85 – 91]

Key words: Ricker population dynamic pool model; summer closed fishing; t_c ; fishery management; the East China Sea

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Effects of different diets on reproductive performance and HUFA composition of Chinese mitten crab (*Eriocheir sinensis*) broodstock during second spawning

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Abstract: Three natural diets (clams, sandworms and trash fish) and one artificial diet were fed to four groups of *Eriocheir sinensis* broodstock for two months. Reproductive performance, larval quality and fatty acid profile of the eggs, gonads and hepatopancreas of the brood crabs were determined during the second spawning period. The HUFA profile of the eggs, ovary and hepatopancreas of the crabs reflected that of the experimental diets, meaning there is an important transfer of nutrients from the exogenous feed to these tissues during secondary ovary maturation. Except the higher survival rate of starved zoea I larvae originating from crabs fed on trash fish, and the bigger egg diameter from crabs fed on clams, no significant differences between treatments were found for any of the other parameters (crab weight, survival and relative fecundity). [Journal of Fishery Sciences of China, 2006, 13(1): 92–99]

Key words: *Eriocheir sinensis*; broodstock nutrition; second spawning; larval quality

CLC number: S963.1 **Document code:** A **Article ID:** 1005–8737–(2006)01–0092–08

Reproductive performance and larval quality are of primary importance for the success of the hatchery to any species^[1]. Although during the last two decades substantial improvements in hatchery techniques have resulted in large numbers of larvae produced, poor and variable survival of the larvae is still one of the major bottlenecks in *Eriocheir sinensis* larval rearing^[2].

E. sinensis is known to be able to fertilize more than one batch of eggs from a single mating^[3]. Like other penaeid shrimp, brood crabs accumulate a lot of energy and nutrients in the hepatopancreas from the exogenous feed during their ovary development, and later on transfer these to the ovaries via haemolymph and thus the developing embryo until egg hatching^[4]. Nutritional requirements of brood crabs can be investigated for both first and second spawning. Depending on the temperature, nutritional and ecologi-

cal conditions, the interval between the first spawned egg hatching and second spawning ranges from 15 to 20 days. After the first spawning, nutrient and energy levels in the spent brood crabs are depleted and need to be replenished during this short period. Generally a lower fecundity and low larval quality has been observed for the second spawning^[5]. Therefore it seems interesting to investigate the effect of diets on reproductive performance and larval quality for the second spawning of *E. sinensis* broodstock.

1 Materials and methods

1.1 Sample

The experiment was carried out at Haifa hatchery, Tanggu, Tianjin, China during the period of February to May, 2004. Three hundred and seventy-six mature crabs (82 males and 294 females) were selected from a farm in Chongming, Shanghai and were

Received date: 2005–01–18; Revised date: 2005–04–29.

Foundation: ICP PhD Grant from the Flemish Interuniversity Council (VLIR), Belgium.

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shipped by air to the hatchery. The average body weight was 68.5 g for male and 116 g for female.

1.2 Experiment design

1.2.1 First spawning After being stocked separately for one week to acclimate to the indoor captive conditions, male and female crabs (in ratio of 1:3) were placed in the same concrete tank containing 20 g/L seawater at 15 °C. After 6 days, 150 berried females were selected and randomly distributed into 5 experimental tanks. Another 30 crabs were kept separately in another tank in order to replace crabs that died due to manipulation. The average body weight of selected spawn crabs was 71.3 g, and the average relative fecundity of the spawn was about 2 578 eggs/g BW. Fiber-glass tanks of 8 m², separated into 4 units with PVC plates, were used as experimental tanks. Each unit had a surface of 2 m². Water depth was kept at 40 cm. Three units within the same tank were used as three replicates for each treatment, each replicate containing 10 crabs. The tanks were covered with a black plastic sheet and three pieces of 1 m long PVC tube were placed in each unit to provide shelter in order to avoid cannibalism. Water parameters were monitored daily. Salt concentration was kept at 20 g/L, pH 8.20–8.30, DO 8.40–8.90 mg/L. Faeces and uneaten feed were removed daily by siphoning. Depending on ammonia and nitrite levels (maximum 1 mg/L and 0.2 mg/L respectively) water was changed every two or three days. The water temperature varied from 15 °C to 17 °C.

Three natural diets and one moist artificial diet were fed to the crabs: clams (*Sinonovacula constricta*, treatment TC), sandworm (*Nereis japonicus*, treatment TS), trash fish (*Chaeturichthys stigmatia*, treatment TT) and an artificial diet (treatment TA). Daily feeding ration was about 10% of total body weight for natural diets and 1%–3% for artificial diet. Feeding was done at 16:00. During the first week, dead crabs were replaced by crabs from the separate tank in order to eliminate mortality due to manipulation.

1.2.2 Second spawning At the beginning of April, the first spawn crabs hatched eggs at 16–

17 °C. From then onwards spent crabs were checked every day for second spawning. The second spawning rate was determined as follows:

$a = b/c \times 100\%$, where a is the second spawning rate, b is the number of second spawning crabs, and c is the number of crabs surviving after the first spawn hatched.

Two berried crabs were sampled from each replicate; (6 ± 2) days after spawning, crabs were weighed (BW) after removing outer water and then total egg mass, gonad and hepatopancreas were removed using tweezers, placed onto blotting paper and weighed to the nearest 0.01 g. Eggs, gonad and hepatopancreas were collected and kept at –20 °C for fatty acid analysis. An egg sample of about 0.010 g was weighed on a digital balance (Mettler AE200) to the nearest 0.0001 g and was separated gently using a needle. The number of eggs in the sample was counted under a binocular microscope (Nikon SMZ645). Fecundity was then calculated by extrapolating the number of eggs in the known mass to the total egg mass. Egg diameter of 100 eggs from each crab was measured using a microscope at 10×10 magnification (Nikon YS100). Relative fecundity of the brood crabs was calculated as follows:

$f_R = N_E/W_C$, where f_R is the relative fecundity, N_E is the number of the eggs, and W_C is the body weight of the crab.

The eggs of the remaining crabs were hatched. Therefore the crabs were placed into individual hatching tanks for larval quality test later.

1.2.3 Larval quality test After hatching, 100 larvae were taken from each tank and were put into beakers containing 500 mL 20 g/L seawater with gentle aeration. Three replicates were conducted from one individual crab. Three crabs from each treatment were tested. The larvae were subsequently starved until they died. Water temperature ranged between 19 °C and 20 °C (ambient temperature). Every day, the water was changed and survival rates were determined.

1.2.4 Analysis of fatty acid Fatty acid composition of tissues was determined by a direct transmethy-

lation method according to a modified procedure of Lepage & Roy (1984)^[6]. The resulting fatty acid methyl ester (FAME) were separated and identified on a HP-5890A gas chromatograph with capillary column SPTM-2330 (Supelco, INC). Identification was based on standard reference mixtures (Nu-Chek-Prep, USA).

1.2.5 Analysis of protein and crude fat Protein content was determined by the Kjeldahl method and crude fat was analysed by the Soxhlet method.

1.3 Statistic

Data were subjected to statistical analysis using the software SPSS. Statistical differences among treatments were determined using one-way ANOVA. Tukey's multiple range test was applied to detect significant differences between means ($P < 0.05$). Per-

centage data were arc-sin transformed prior to analysis.

2 Results

2.1 Feed composition

Among the experimental diets, trash fish contained the highest protein level (81.32%), whereas artificial diets contained the lowest (34.93%) (Tab.1). Total lipid level in the artificial diet was the highest (12.23%), and the others ranged from 7% to 9%. Also the fatty acid profile of the experimental diets varied considerably. The EPA content ranged from 3.95 mg/g (DW) in trash fish to 7.94 mg/g DW in sandworms; the DHA content ranged from 1.04 mg/g DW in sandworms to 9.70 mg/g DW in the artificial diet; the DHA/EPA ratio ranged from 0.13 in trash fish to 1.47 in the artificial diet.

Tab.1 Proximate composition and fatty acid profile of the experimental diets

表 1 试验饲料组分和脂肪酸组成

Item	Clam	Trash fish	Sandworm	Artificial diet
Moisture/% 水分	85.27	78.54	86.42	30.34
Protein/% of DW 蛋白质	56.55	81.32	53.39	34.93
Crude fat/% of DW 粗脂肪	7.78	7.52	9.02	12.23
Fatty acids/(mg·g ⁻¹ DW) 脂肪酸				
18:2n6	0.52	0.58	0.41	5.79
18:3n3	1.19	0.11	0.34	1.67
18:4n3	4.12	0.37	1.36	1.61
20:4n6 (ARA)	1.69	1.63	0.75	2.45
20:5n3 (EPA)	4.52	3.95	7.94	6.61
22:6n3 (DHA)	3.91	4.13	1.04	9.70
DHA/EPA	0.87	1.05	0.13	1.47
Total HUFA *	10.12	9.71	9.73	18.76

* Total HUFA = ARA + EPA + DHA

2.2 Broodstock performance

There were no significant differences among treatments on crab body weight (Tab.2). Although TS and TT resulted in higher relative fecundities than TA and TC, there was no statistically significant difference among treatments due to the high variation within treatments. Average egg diameter in treatment TC was significantly higher than those in treatments TT and TA, whereas TS had intermediate val-

ues. Although TT gave a higher broodstock survival rate at 12 and 20 days after the first spawn hatched, there were no statistically significant differences in survival rate among the treatments due to the high variation. By the time the second spawn hatched, the survival rate in all treatments had dropped to 2%. 100% of the crabs had spawned for the second time 20 days after the first spawn.

Tab.2 Average body weight (BW), relative fecundity, egg diameter and survival rate of second spawning *Eriocheir sinensis* broodstock fed on different experimental diets表2 投喂不同试验饲料的中华绒螯蟹二次抱卵期间平均体重、相对怀卵量、卵径和成活率 $\bar{X} \pm SD$

Treatment	Body weight/g	Relative Fecundity ($\text{egg} \cdot \text{g}^{-1} \text{BW}$)	Egg diameter /mm	Survival/% (after first spawn hatched)		
				12 day	20 day	30 day
TC	74.79 \pm 2.99	2203 \pm 350	4.63 \pm 0.12 ^a	78 \pm 18	32 \pm 8	2 \pm 0
TS	68.70 \pm 3.55	2952 \pm 413	4.35 \pm 0.06 ^{ab}	68 \pm 16	34 \pm 26	2 \pm 0
TT	70.72 \pm 3.72	2929 \pm 275	4.20 \pm 0.04 ^b	84 \pm 6	48 \pm 27	2 \pm 0
TA	72.47 \pm 11.87	2435 \pm 427	4.21 \pm 0.13 ^b	57 \pm 7	41 \pm 27	2 \pm 0

Note: 1) Values in the same column showing a different superscript are significantly different ($P < 0.05$).

2) TC—*E. sinensis* broodstock fed with clams (*Sinonovacula constricta*), TS—*E. sinensis* broodstock fed with sandworm (*Nereis japonicus*), TT—*E. sinensis* broodstock fed with trash fish (*Chaeturichthys stigmatias*), TA—*E. sinensis* broodstock fed with artificial diet.

注: 1) 同一列中标有不同上标的数值具有显著差异 ($P < 0.05$).

2) TC—投喂蜆蜆(*Sinonovacula constricta*)的中华绒螯蟹亲蟹, TS—投喂沙蚕(*Nereis japonicus*)的中华绒螯蟹亲蟹, TT—投喂杂鱼(*Chaeturichthys stigmatias*)的中华绒螯蟹亲蟹, TA—投喂人工饲料的中华绒螯蟹亲蟹。

2.3 Larval quality

The survival rate of starved zoea I larvae from *E. sinensis* broodstock fed on different experimental diets is shown in Fig.1. The starved zoea I larvae were not able to develop into stage zoea II, no matter how long they survived. Treatment TT gave the best quality larvae. In this treatment 50% of the starved larvae could survive for 7 days after hatching (DAH), whereas only a small percentage of the larvae from TC and TS could survive until DAH 7 and larvae of treatment TA could only survive to DAH 5.

2.4 Fatty acid profile of gonads, hepatopancreas and eggs

The fatty acid composition, and more specifically the DHA and the EPA contents in hepatopancreas, gonads and eggs reflected the composition of the diets (Tab.3). Among treatments, eggs, gonads and hepatopancreas from crabs of treatment TS had the highest EPA content (18.95 mg/g DW, 16.26 mg/g DW and 8.60 mg/g DW respectively), whereas crabs from treatment TT gave the lowest EPA value (11.60 mg/g DW, 10.51 mg/g DW and 6.07 mg/g DW respectively). On the other hand, TS resulted in the lowest DHA values in eggs, gonads and hepatopancreas (3.08 mg/g DW, 2.60 mg/g DW and 0.81 mg/g DW, respectively), whereas TA resulted in the highest DHA values (12.82 mg/g DW, 6.75 mg/g DW and 11.37 mg/g DW, respectively).

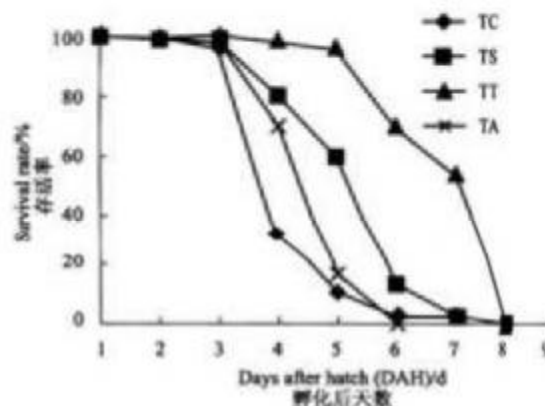


Fig.1 Survival rate of starved zoea I larvae of *Eriocheir sinensis* obtained from second spawning broodstock fed with different experimental diets

Note: TC—*E. sinensis* broodstock fed with clams (*Sinonovacula constricta*), TS—*E. sinensis* broodstock fed with sandworm (*Nereis japonicus*), TT—*E. sinensis* broodstock fed with trash fish (*Chaeturichthys stigmatias*), TA—*Eriocheir sinensis* broodstock fed with artificial diet.

图1 投喂不同试验饲料的二次抱卵中华绒螯蟹亲蟹所产幼体在饥饿状态下的成活率

注: TC—投喂蜆蜆(*Sinonovacula constricta*)的中华绒螯蟹亲蟹, TS—投喂沙蚕(*Nereis japonicus*)的中华绒螯蟹亲蟹, TT—投喂杂鱼(*Chaeturichthys stigmatias*)的中华绒螯蟹亲蟹, TA—投喂人工饲料的中华绒螯蟹亲蟹。

Overall DHA content in both gonad and egg were less than EPA content in any treatment. In order to identify the correlation between dietary fatty acid profile and tissue fatty acid profile, linear regression analyses

of tissue DHA and EPA content against dietary EPA and DHA contents were performed and shown in Fig.2. The result showed that EPA and DHA con-

tent in eggs, and DHA content in hepatopancreas were significantly affected by the dietary EPA and DHA contents ($R^2 > 0.90$).

Tab.3 EPA and DHA contents in eggs, gonads and hepatopancreas of second spawning

Eriocheir sinensis broodstock fed on different experimental diets

表3 投喂不同试验饲料的中华绒螯蟹亲蟹二次抱卵期间卵、卵巢及肝胰腺的 EPA 和 DHA 含量

$n = 6$, $\bar{X} \pm SD$, mg/g DW

Fatty acids	Treatment	Eggs	Gonads	Hepatopancreas
EPA	TC	13.66 ± 2.58	10.93 ± 2.43	6.96 ± 1.53
	TS	18.95 ± 1.96	16.26 ± 1.78	8.60 ± 0.73
	TT	11.60 ± 2.39	10.51 ± 0.94	6.07 ± 0.71
	TA	15.83 ± 2.70	9.95 ± 2.38	9.64 ± 0.85
DHA	TC	8.90 ± 1.84	5.75 ± 1.45	2.95 ± 1.37
	TS	3.08 ± 0.55	2.60 ± 0.64	0.81 ± 0.21
	TT	7.52 ± 2.17	5.24 ± 0.97	4.83 ± 0.94
	TA	12.82 ± 2.40	6.75 ± 1.96	11.37 ± 0.81

Note: TC—*E. sinensis* broodstock fed with clams (*Simmonsia constricta*), TS—*E. sinensis* broodstock fed with sandworm (*Nereis japonicus*), TT—*E. sinensis* broodstock fed with trash fish (*Chaeturichthys stigmatias*), TA—*E. sinensis* broodstock fed with artificial diet.
注: TC—投喂扇贝(*Simmonsia constricta*)的中华绒螯蟹亲蟹, TS—投喂沙蚕(*Nereis japonicus*)的中华绒螯蟹亲蟹, TT—投喂杂鱼(*Chaeturichthys stigmatias*)的中华绒螯蟹亲蟹, TA—投喂人工饲料的中华绒螯蟹亲蟹。

3 Discussion

The HUFA profile of the eggs, gonads and hepatopancreas of second spawning *E. sinensis* broodstock very well reflected that of the experimental diets (Fig.2). This shows that, despite the large amounts of nutrients accumulated during the first ovarian maturation process, after first spawning, crabs need to take up a lot of energy and nutrients from exogenous diets to replenish its reserves, and transfer them via the hepatopancreas to the ovaries for secondary maturation. In this respect, the results from this study are in agreement with studies in other crustaceans, e.g. *Penaeus monodon*^[7], *Fenneropenaeus chinensis*^[8], *Litopenaeus vannamei*^[9], *Macrobrachium rosenbergii*^[10] and *Scylla paramamosain*^[11].

Furthermore the HUFA profile of these tissues probably is not merely influenced by the dietary HUFA level, but probably points out a specific requirement for these fatty acids^[8,12]. In this respect, it was noted that the DHA and EPA contents increased from the hepatopancreas, over gonad, to eggs,

whereas the hepatopancreas had levels close to those of the diets, moreover DHA contents in both gonad and hepatopancreas were less than the EPA contents in any treatment. It is well understood that the hepatopancreas of crustaceans acts as a storage organ for dietary lipids prior to its mobilization and incorporation in specific tissues^[7]. Although crustaceans have a limited ability to elongate fatty acids and eventually synthesize a certain amount of fatty acids de novo^[13], the major part of the accumulated lipids in gonads and eggs originate from the diets through selective absorption. As the lipids in the ovaries and eggs contain a higher proportion of n-3 HUFA, particularly EPA and DHA than those of the hepatopancreas, it is believed that they also play a crucial role in mitten crab reproduction^[14]. Studies on broodstock rearing of Chinese mitten crab^[15] using artificial diets showed a high correlation between n-3 HUFA content in the eggs and reproductive performance of the broodstock. Xu et al.^[8] suggested that EPA may play some specific role in the ovarian development process relating to fecundity, whereas DHA may play some other role

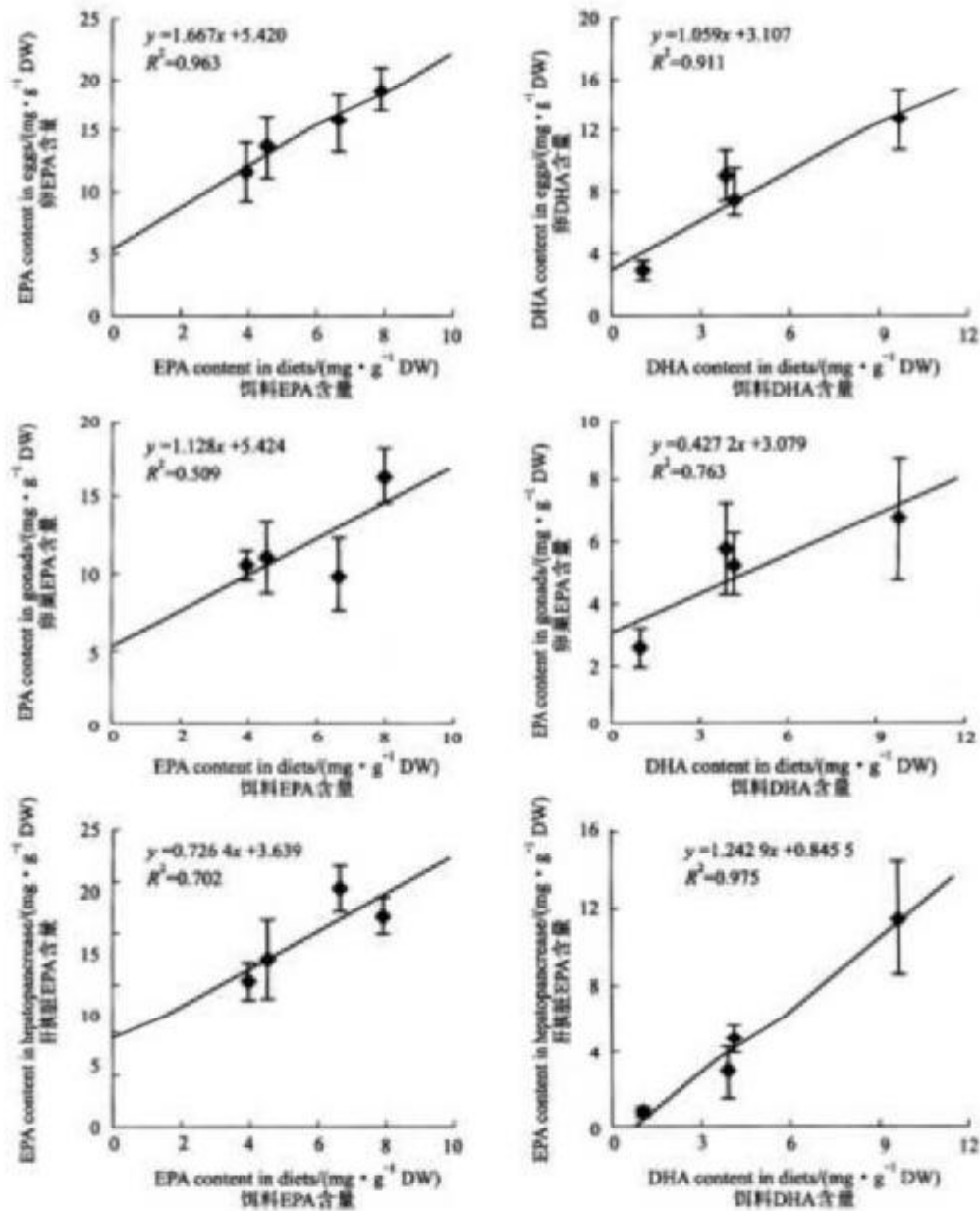


Fig. 2 Linear regression analysis of relationships between EPA, DHA content of diets and that in eggs, gonads and hepatopancreas of second spawning *E. sinensis* broodstock ($n=6$)

Note: TC—*E. sinensis* broodstock fed with clams (*Sinonovacula constricta*), TS—*E. sinensis* broodstock fed with sandworm (*Nereis japonicus*), TT—*E. sinensis* broodstock fed with trash fish (*Chaeturichthys stigmatias*), TA—*E. sinensis* broodstock fed with artificial diet.

图2 试验饵料中 EPA、DHA 含量与二次抱卵期间中华绒螯蟹的卵、卵巢和肝胰腺中 EPA、DHA 含量的相关性线性回归分析

注: TC—投喂缢蛏(*Sinonovacula constricta*)的中华绒螯蟹亲蟹, TS—投喂沙蚕(*Nereis japonicus*)的中华绒螯蟹亲蟹, TT—投喂杂鱼(*Chaeturichthys stigmatias*)的中华绒螯蟹亲蟹, TA—投喂人工饵料的中华绒螯蟹亲蟹。

in early embryogenesis which related to egg hatchability of larval *Penaeus chinensis*. Our results showed that both EPA and DHA are important to ovary development and reproduction of Chinese mitten crab, of which EPA seems more crucial. However, no clear correlation could be obtained in this study. It should be however noted that the different diets tested in this study, not only differed in HUFA content, but had a completely different gross (proteins, total lipids, etc.) as well as micro-nutrient (vitamins, minerals, sterols, phospholipids, carotenoids, etc.) composition. Therefore it is difficult to draw any definite conclusions. Moreover the reproductive performance of second spawning broodstock should also relate to that of first spawning. Unfortunately we did not record much data on the first spawning.

In all treatments mortality after second spawning was very high, especially upon hatching of the second spawn. This phenomenon is often observed in hatcheries. After two times of spawns the crabs have consumed a lot of their energy and nutrient reserves, hence they are nearly exhausted. From a nutritional point of view, this study shows that essential nutrients, e.g. HUFA, can be supplemented through artificial diets to further enhance *Eriocheir sinensis* broodstock performance.

Acknowledgements

This study was supported by an ICP PhD grant from the Flemish Interuniversity Council (VLIR, Belgium) for the second author. The authors would like to express their gratitude to Tianjin Haifa Seafood Industry and Development Co., Ltd. for providing experimental facilities and assistance in the practical work.

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