第15卷第4期 中国水产科学 Vol.15 No.4
2008年7月 Journal of Fishery Sciences of China July 2008

桁拖网不同网目结构的网囊对虾类的选择性

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摘要：为改善东海近海桁拖网对主要虾类的选择性，使用对比作业法，在吕泗渔场开展了多个航次、不同网目结构（菱形、方形及转向网目）网囊的选择性试验，并进行了选择性分析。在选择性分析中，将几何相似原理运用于选择性曲线模型（Richards 曲线），并使用极大似然估计法进行参数估计，同时使用假设检验理论对选择性曲线模型进行简化。选择性模型对哈氏仿对虾（*Parapenaeopsis hardwickii*）和葛氏长臂虾（*Palaemon gravier*）渔获数据的拟合结果显示，选择性模型具有较好的拟合性，但存在航次间差异；不同网目结构网囊的选择性曲线模型都可简化为 Logistic 曲线；对于哈氏仿对虾，相比菱形网目网囊，方形网目和转向网目网囊的 L_{50} 较大，而 SR 较小（菱形和方形网目之间差异显著，菱形和转向网目之间差异不显著）；对于葛氏长臂虾，方形网目和转向网目网囊的 L_{50} 较大（菱形和方形网目之间差异显著，菱形和转向网目之间差异不显著）。根据虾类在网囊中的逃逸行为，方形网目、转向网目具有较好选择性的原因在于这 2 种网目较传统菱形网目不易合拢；不同网目结构网囊的选择性对开展渔具种类选择性研究具有重要意义。[中国水产科学，2008，15(4)：667-676]

关键词：尺寸选择性；多囊桁拖网；哈氏仿对虾；葛氏长臂虾；菱形网目；方形网目；转向网目（T90）
中图分类号：S97 **文献标识码：**A **文章编号：**1005-8737-(2008)04-0667-10

从 20 世纪 70 年代开始，中国东海近海捕虾桁拖网渔业迅猛发展，成为东海区主要的作业方式之一[1-2]。然而，同世界许多捕虾拖网渔业一样，桁拖网网囊网目尺寸较小（网目内径不到 25 mm），在其渔获物组成中，未达成熟体长的经济幼鱼、幼虾占有相当大的比例[3-4]，兼捕和抛弃问题严重，对近海渔业资源造成了严重的影响。

改善捕虾拖网渔具对捕捞对象尺寸的选择性、实现渔业的选择性捕捞是减轻渔业兼捕问题、保护渔业资源的主要手段之一[5-6]。影响捕虾拖网网囊网目尺寸选择性的因素有很多，除了网目尺寸以外，很多研究表明，网目结构（网目形状）也是影响网囊网目尺寸选择性的重要因素[7-8]。传统的菱形网目网囊在水流作用下不易张开，影响了进入网囊的渔获逃逸；相比而言，方形网目网囊具有较好的选择性能[9-12]，且已在国外捕虾拖网渔业中得到了普遍使用，例如挪威和瑞典规定斯卡格拉克海峡和卡特加特海峡作业的海螯虾（*Nephrops norvegicus*）拖网渔船必须使用网目尺寸大于 70 mm 的方形网目网囊[13]；除方形网目以外，将传统菱形网目转向 90°（T90，Turned through 90°）后使用可以改善网囊对捕捞对象的尺寸选择性[14-15]，但是相关研究尚未在捕虾拖网渔业中进行。

孙满昌和王玉明[3]、孙满昌等[4]在浙江嵊泗、江苏启东等地开展了桁拖网渔具菱形网目网囊选择性研究，认为在网目尺寸方面，将现行渔具网囊网目尺寸从 20~30 mm 增大至 35~40 mm 是有必要的；在前期研究基础上，笔者从 2005 年年底开始在吕泗渔场开展了不同网目尺寸、不同网目结构网囊选择性海上生产试验，旨在进一步了解和掌握桁拖网渔具对主要渔获种类的尺寸选择性，特别是网目结构对捕虾桁拖网选择性能的影响，为深入开展桁拖网渔具的渔获性能优化研究提供基础，为有关渔业管理部门制定相关规定提供参考。

1 材料与方法

1.1 作业时间、海域、试验渔船及渔具

桁拖网渔具选择性海上生产试验共分为 4 个航次，各航次作业时间、作业区域及海上生产试验的基本情况如表 1 所示。

收稿日期：2007-10-29；**修订日期：**2008-01-28.
基金项目：教育部高等学校博士学科点专项科研基金（20050264004）；国家科技支撑计划（2006BAD09A05）；上海市重点学科建设项目（T1101）.
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表 1 海上试验基本情况

Tab.1 Basic information of sea trial for size selectivity experiments

航次 Trip	作业时间 Fishing period	作业区域 Fishing region	水深 /m Depth	流速 /kn Flow velocity	拖速 /kn Haul velocity	作业网次数 Number of hauls		
						菱形网目 Diamond mesh	方形网目 Square mesh	转向网目 T90 mesh
1	2005.10.29–2005.11.05	32° 15′ N–32° 39′ N 121° 38′ E–122° 30′ E	18–28	1.3–1.5	2.2–2.9	5	5	–
2	2006.3.17–2006.03.22	32° 02′ N–32° 17′ N 122° 32′ E–122° 55′ E	26–32	1.4–1.7	2.2–2.7	5	–	5
3	2006.09.01–2006.09.07	32° 42′ N–33° 02′ N 122° 12′ E–122° 31′ E	22–26	0.8–1.0	2.1–2.4	5	5	–
4	2006.12.23–2006.12.28	32° 32′ N–32° 52′ N 122° 32′ E–122° 56′ E	25–34	1.5–1.8	2.1–2.4	–	–	6

在第 1、2 航次，试验渔船为群众作业渔船“苏常渔 02121”号，该船全长 33.0 m，型宽 6.4 m，排水量 130 t，主机功率 205 kW，使用该船平时作业桁拖网为试验网具（图 1–A），该网具配备桁杆长度为 32.0 m，网具拉直长度为 15.5 m，网具装配 8 个网囊；试验第 3、4 航次试验渔船为启东市渔船“苏启渔 1207”号，该船排水量为 52 t、主机功率 120 kW，同样使用该船作业桁拖网作为试验网具（图 1–B），该网具配备桁杆长度为 22.0 m，网具拉直长度为 15.4 m，网具装配 6 个网囊。网次作业时间在 3.25~4.50 h 之间，平均约为 4 h。

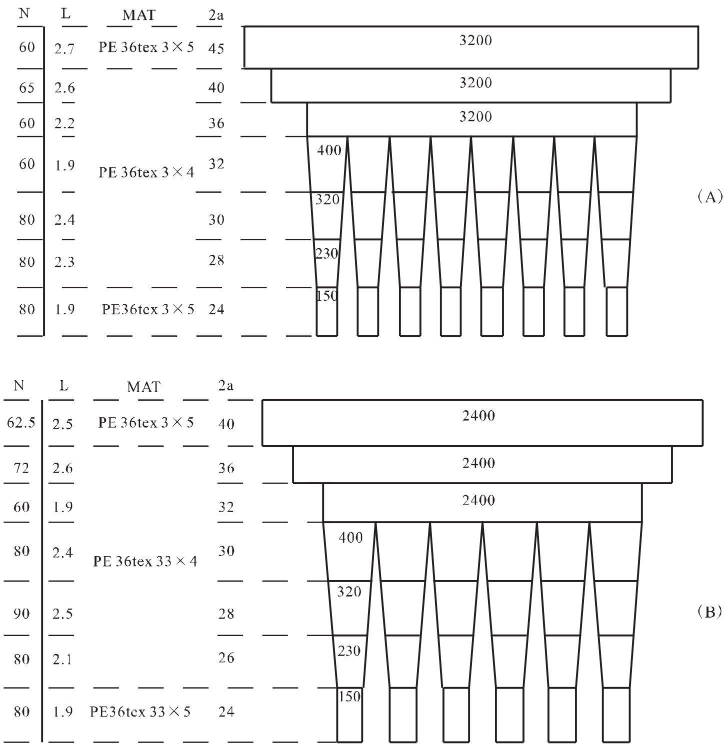

图 1 试验网具网具网衣展开图

(A) 为第 1、2 航次试验网，(B) 为第 3、4 航次试验网，N 为纵网目数，L 为拉紧长度，MAT 为网线材料，2a 为网目尺寸 .

Fig.1 Net drawing of the experimental fishing gears

(A): beam trawl used in the 1st and 2nd trials, and (B) used in the 3rd and 4th trials. N stands for number of meshes; L stands for stretched length; MAT stands for material of twine; 2a stands for mesh size.

1.2　试验方法

根据东海近海桁拖网渔具多囊结构的特点，采用对比试验法进行网目网囊尺寸选择性试验，即在网具不同网囊位置，安装不同网目尺寸的网囊进行作业，通过比较不同网囊的渔获物组成来分析网囊对渔获种类的尺寸选择性，采用网目内径为 20 mm 的菱形网目网囊作为对照网囊。

不同航次开展的选择性试验内容如表 1 所示。菱形网目网囊试验选用了 30 mm、35 mm 和 40 mm 网目尺寸试验网囊，在试验的第 1、2 和 3 航次共进行了 15 个有效网次的试验；方形网目网囊试验选用了 30 mm、35 mm 和 40 mm 网目尺寸试验网囊，在试验的第 1 和 3 航次共进行了 10 个有效网次的试验；转向网目网囊试验选用了 30 mm 和 40 mm 网目尺寸试验网囊，在试验的第 2 和 4 航次共进行了 11 个有效网次的试验；不同网目结构的网目及网囊规格如表2所示。试验网囊网衣均为机织网片，网线材料为 42texPE3×5；与平常作业一样，在网囊头前部安装网目长度为 25 mm（网线材料为 PE）的滤网（俗称“倒须”），防止进入网囊的渔获倒退到网身部，并在网囊的网腹上安装加强网片防止网囊网衣的破裂。

表 2　试验网囊和对照网囊规格

Tab.2　Specification of the experimental and test codends

网目结构 Mesh Construction	网囊位置 * Codend position		网目内径 /mm Inner diamater		网囊规格 /mesh** Codend dimension	
	第 1、2 航次 1st and 2nd trips	第 3、4 航次 3rd and 4th trips	名义尺寸 Nominal size	实测值 Actual measure $\bar{X}$±SD	横向 Width	纵向 Length
菱形 Diamond	2	2	对照网囊 Control net	20.21±0.63	180	96
	4	3	30	29.85±0.85	120	64
	5	4	35	34.94±0.75	102	54
	7	5	40	39.84±0.88	90	48
方形 Square	2	2	对照网囊 Control net	20.07±0.51	90	190
	4	3	30	29.42±0.33	60	124
	5	4	35	35.10±0.40	50	106
	7	5	40	40.09±0.68	45	94
转向 T90	2	2	对照网囊 Control net	20.22±0.24	140	115
	4	3	30	29.97±0.57	82	64
	6	5	40	39.69±0.44	70	58

注：“*”指网囊的安装位置，例如“4”表示该网囊安装于网具自艏至艉方向的第 4 网囊；“**”指方形网目网囊规格的单位为单脚 .

Note: * Rigging position of the experimental codends, e.g. “4” means the codends was rigged in the 4th positon in the direction from bow to stern; ** Units of codend dimension are meshes for diamond and Turn 90°　meshes, while bars for square mesh.

起网后，对各试验网囊虾类渔获按 1/8 的取样比例进行取样，并对取样渔获进行分类统计，测量虾类个体全长（眼球至尾节末端的距离），按 5 mm 的间隔分组。

1.3　分析方法

1.3.1　选择性模型及参数估算方法　网囊尺寸选择性分析采用张健和孙满昌[16]提出的运用几何相似原理进行的过滤性渔具选择性分析方法，即认为不同网目尺寸网囊的选择性曲线几何相似，各网囊的选择性曲线为：

$$S_{ij}=\left[\frac{\exp(a+b\dfrac{l_j-l_0}{m_i})}{1+\exp(a+b\dfrac{l_j-l_0}{m_i})}\right]^{\frac{1}{\delta}} \tag{1}$$

式中：$\theta=(a,\ b,\ \delta,\ l_0)$，模型参数；$l_j$ 表示第 j 组渔获体长；m_i 表示第 i 网囊的网目尺寸。

各网囊选择性参数 L_{50}（50％选择体长）和 SR（选择范围）分别为：

$$L_{50i}=\frac{-m_i}{b}[\ln(2^{\delta}-1)+a]+l_0 \tag{2}$$

$$\begin{aligned}SR_i &= L_{75i} - L_{25i} \\ &= \frac{m_i}{b}[\delta \ln 3 + \ln(4^{\delta} - 1) - \ln(4^{\delta} - 3^{\delta})]\end{aligned} \tag{3}$$

使用极大似然估计法估算模型参数，即通过最大化对数似然函数估算模型参数，

$$\begin{aligned}\ln L &= \sum_{i=1}^{I}\sum_{j=1}^{J}(c_{ij} \cdot \ln \frac{\phi_{ij}}{\sum_{i=1}^{I}\phi_{ij}}) \\ &= \sum_{i=1}^{I}\sum_{j=1}^{J}(c_{ij} \cdot \ln \frac{P_i S_{ij} Q_{ij} E_i}{\sum_{i=1}^{I} P_i S_{ij} Q_{ij} E_i})\end{aligned} \tag{4}$$

式中：c_{ij} 表示第 i 网囊捕获的第 j 体长组的渔获数量；P_i 表示第 i 网囊的渔获能力（$\sum_{i=1}^{I} P_i = 1$），E_i 表示第 i 网囊的捕捞努力量，Q_{ij} 表示对第 i 网囊捕获的第 j 体长组渔获的取样比例；I、J 分别表示网囊总数及体长组总数。

利用 MS EXCEL 软件附带的"规划求解"功能实现对数似然函数的最大化。在极大似然估计法进行模型参数估算时，利用 Fisher 信息矩阵估算各模型参数的方差，并利用 delta 方法估算选择性参数 L_{50} 和 SR 的方差[17-18]。

选择性分析采用联合各航次渔获数据进行选择性分析的方法，即将各航次得到的渔获取样数据累加，进行选择性分析；由于选择性试验分为 4 个航次，使用过渡离散的重复估计 (Replication estimation of overdispersion，REP) 方法来考虑航次间差异[19-20]，其中

$$REP = \frac{Q}{d} \tag{5}$$

式中：Q 表示模型拟合的皮尔逊卡方统计量，d 表示自由度，

$$Q = \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}\frac{(c_{ijk} - \hat{c}_{ijk})^2}{\hat{c}_{ijk} \cdot (1 - \hat{\phi}_{ik})} \tag{6}$$

式中：c_{ij}、$\hat{c}_{ijk}$ 分别表示第 k 航次第 i 网囊捕获的第 j 体长组的渔获取样数量和期望渔获数量；K 表示试验航次数；$d=(I-1)\cdot(K-1)\cdot J'$，$J'$ 表示单一体长组总渔获 $\sum_{i=1}^{I} c_{ij}$ >网次数量的渔获体长组数。如果联合各航次的渔获数据的选择性分析结果没有显著差异，则 Q 应服从自由度为 d 的 χ^2 分布，如果这一假设被拒绝，则联合各航次进行分析的模型参数及选择性参数的标准差应乘以 $\sqrt{REP}$。

1.3.2 模型拟合优劣性判断及模型简化 若选择性模型正确，那么模型拟合偏差统计量 D^2 应服从自由度为 $(I-1)\times J' - n$ 的 χ^2 分布[19-20]，以此判断模型拟合优劣性，其中 n 为模型参数个数

$$D^2 = 2 \times \sum_{i=1}^{I}\sum_{j=1}^{J}(c_{ij} \cdot \ln \frac{c_{ij}}{\hat{c}_{ij}}) \tag{7}$$

使用假设检验理论对选择性曲线模型进行简化[16]，包括

H_{0A}: δ=1，即单个网囊选择性曲线简化 Logistic 曲线；

H_{0B}: l_0=0，即选择性曲线是相对体长的函数。

若模型可简化，则简化模型与完整模型残差之差应服从模型自由度之差的 χ^2 分布，通过这一原理判别模型是否可以简化[19]。

2 结果与分析

2.1 渔获数据

各航次渔获组成有较大差异，在虾类渔获中，除哈氏仿对虾 (*Parapenaeopsis hardwickii*) 和葛氏长臂虾 (*Palaemon gravieri*) 作为主捕虾类在各航次均有较多渔获以外，其余虾类 [（脊尾白虾 *Exopalaemon carinicauda*），中华管鞭虾 (*Solenocera crassicornis* 等）] 的取样渔获不足以进行选择性分析。不同网目结构的网囊捕获的虾类渔获量如表 3 所示，不同虾类取样渔获体长分布如图 2 所示。

表 3 不同网目结构网囊的虾类网次平均质量

Tab.3 Average weights per haul of shrimps retained by codends with different mesh configuration $\bar{X}\pm$SD

渔获种类 Species	网目结构 Mesh construction	网目尺寸 /mm Mesh size 30	35	40	控制网囊 Control codend
哈氏仿对虾 *Parapenaeopsis hardwickii*	菱形 Diamond	3.1±0.21	1.79±0.29	1.05±0.43	4.73±0.82
	方形 Square	2.17±0.39	0.91±0.12	0.33±0.16	4.85±1.10
	转向 T90	2.93±0.39	–	0.46±0.19	5.20±0.66
葛氏长臂虾 *Palaemon gravieri*	菱形 Diamond	1.51±0.42	0.68±0.26	0.25±0.10	2.14±0.67
	方形 Square	1.05±0.25	0.39±0.22	0.12±0.09	1.97±0.53
	转向 T90	1.23±0.29	–	0.19±0.14	2.56±0.35

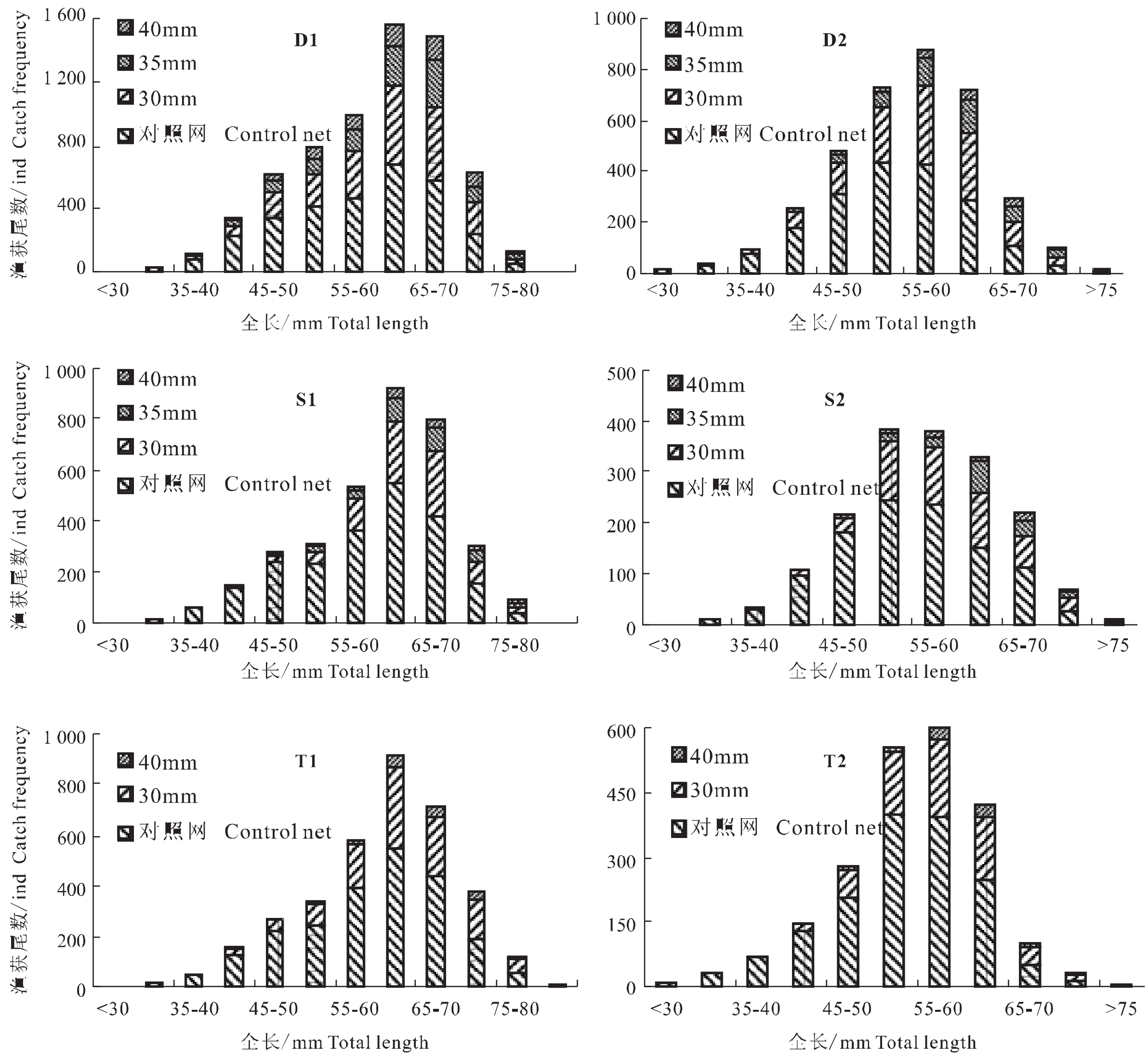

图 2　不同网目结构网囊的渔获体长分布

D1：菱形网目网囊哈氏仿对虾渔获；S1：方形网目网囊哈氏仿对虾渔获；T1：转向网目网囊哈氏仿对虾渔获；D2：菱形网目网囊葛氏长臂虾渔获；S2：方形网目网囊葛氏长臂虾渔获；T2：转向网目网囊葛氏长臂虾渔获 .

Fig.2　Size frequency of shrimp catches subsampled from codends with different mesh construction

D1：*Parapenaeopsis hardwickii* sumsampled from diamond mesh codends；S1：*Parapenaeopsis hardwickii* from square mesh codends；T1：*Parapenaeopsis hardwickii* from T90 mesh codends；D2：*Palaemon gravier* from diamond mesh codends；S2：*Palaemon gravier* from square mesh codends；T2：*Palaemon gravier* from T90 mesh codends.

2.2 模型拟合及简化

在进行模型拟合前，对数似然函数公式 (4) 可进行简化：首先，由于采用相同的取样比例进行渔获取样，因此 (4) 式中，Q_{ij} 可以忽略；其次，在作业过程中，桁拖网多囊结构不仅保证了各网囊的捕捞努力量完全一致（忽略 E_i），还使得各网囊的渔获过程具有相对独立性，而且网囊的前端都安装了漏斗网，因此可以假设各网囊具有相同作业强度（忽略 P_i），这样对数似然函数被简化为 $\ln L=\sum_{i=1}^{I}\sum_{j=1}^{J}(c_{ij}\cdot\ln\frac{S_{ij}}{\sum_{i=1}^{I}S_{ij}})$，其中对照网囊的选择性 S_{ij}=1。

对于哈氏仿对虾、葛氏长臂虾，使用选择性模型拟合不同网目结构网囊的渔获数据，并对选择性模型进行简化，发现选择性模型接受 H_{0A} (δ=1) 假设 (P > 0.05)，但均拒绝假设 (P < 0.000 1)；方形网目网囊对葛氏长臂虾渔获数据的模型拟合结果显示缺乏一定的拟合性 (P=0.047)，但是不影响模型的简化结果 (H_{0A} 简化 P=0.071)。不同网目结构网囊的选择性模型拟合及简化结果如表 4 和表 5 所示。

各网目结构网囊的选择性模型拟合在不同试验航次之间都存在差异 (P<0.000 1)，因此模型参数（及选择性）估计值的标准差都乘以$\sqrt{\text{REP}}$，忽略航次间的差异将会低估模型参数及选择性参数的标准差。

2.3 不同网目结构网囊的选择性参数比较

根据选择性模型拟合及简化结果，不同网目结构、不同网目尺寸的网囊对虾类的选择性参数 L_{50}、SR 及其与网目尺寸的线性关系如表 6 所示。

从表 6 可以发现，对于哈氏仿对虾，各网目尺寸的方形网目网囊的 L_{50} 显著大于相应网目尺寸菱形网目网囊的 L_{50}（平均相差 15.6%，P=0.021），而选择范围 SR 显著小于菱形网目网囊（平均相差 38.0%，差异显著，P=0.007）；转向网目网囊的 L_{50} 比菱形网目网囊的大 14.2%，而 SR 小 26.6%，但差异均不显著 (P 值分别为 0.092 和 0.091)；方形网目网囊与转向网目网囊的选择性参数差异不大。

表 4 不同网目结构网囊对哈氏仿对虾的模型拟合、简化及模型参数

Tab.4 Goodness of model fit and simplification and estimates (with standard errors) of model parameters for *Parapenaeopsis hardwickii*

项目 Item	系数 Index	菱形网目 Diamond mesh		方形网目 Square mesh		转向网目 T90 mesh	
		完整模型 Full model	H_{0A}	完整模型 Full model	H_{0A}	完整模型 Full model	H_{0A}
模型参数 Model estimates $\bar{X}\pm$SD	$\hat{a}$	−9.76±3.24	−7.35±0.40	−8.48±3.24	−10.11±0.64	−8.21±4.04	−10.84±0.83
	$\hat{b}$	2.75±0.83	2.17±0.22	3.04±0.96	3.51±0.36	2.44±0.88	2.96±0.48
	$\hat{\delta}$	1.52±0.70	1	0.78±0.43	1	0.64±0.53	1
	$\hat{l}_0$	−46.88±11.02	−48.80±11.02	−21.81±9.00	−21.37±8.92	−47.11±15.75	−48.98±16.40
模型拟合 Model fit	模型偏差 Deviance	29.48	30.90	22.57	23.11	15.56	16.80
	自由度 Degree of freedom	26	27	26	27	16	17
	P	0.290	0.275	0.657	0.679	0.484	0.468
模型简化 Model simplification	模型偏差 Deviance	–	1.417	–	0.540	–	1.233
	自由度 Degree of freedom	–	1	–	1	–	1
	P	–	0.234	–	0.463	–	0.267
航次间差异 Between-trials variation	Q	108.85	110.94	64.16	65.04	61.54	62.96
	d	56	57	26	27	16	17
	$\sqrt{\text{REP}}$	1.39	1.40	1.57	1.55	1.96	1.92
	P	<0.0001	<0.0001	<0.0001	0.0001	<0.0001	<0.0001

表 5 不同网目结构网囊对葛氏长臂虾的模型拟合、简化及模型参数

Tab.5 Goodness of model fit and simplification and estimates (with standard errors) of model parameters for *Palaemon gravieri*

项目 Item	系数 Index	菱形网目 Diamond mesh 完整模型 Full model	菱形网目 Diamond mesh H_{0A}	方形网目 Square mesh 完整模型 Full model	方形网目 Square mesh 完整模型 Full model	转向网目 T90 mesh H_{0A}	转向网目 T90 mesh 完整模型 Full model
模型参数 Model estimates $\overline{X}\pm$SD	$\hat{a}$	−11.34±3.81	−12.50±0.87	−8.80±4.32	−13.73±1.45	−5.60±5.13	−10.68±1.20
	$\hat{b}$	3.67±1.12	4.00±0.46	3.35±1.29	4.80±0.83	2.29±1.15	3.43±0.79
	$\hat{\delta}$	0.86±0.46	1	0.49±0.42	1	0.35±0.59	1
	l_0	−44.03±10.32	−43.45±9.99	−30.14±12.36	−29.54±12.55	−31.91±17.94	−35.60±20.44
模型拟合 Model fit	模型偏差 Deviance	20.17	20.43	39.14	42.40	12.68	15.77
	自由度 Degree of freedom	23	24	26	27	14	15
	P	0.632	0.672	0.047	0.030	0.552	0.398
模型简化 Model simplification	模型偏差 Deviance	–	0.262	–	3.254	–	3.084
	自由度 Degree of freedom	–	1	–	1	–	1
	P	–	0.609	–	0.071	–	0.079
航次间差异 Between-trials variation	Q	150.01	150.12	80.58	85.53	70.16	73.29
	d	50	51	23	24	14	15
	$\sqrt{\text{REP}}$	1.73	1.72	1.87	1.89	2.24	2.21
	P	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

表 6 不同网目结构网囊对虾类的选择性参数

Tab.6 Selectivity parameters (with standard errors) of codends with different mesh size and mesh constructure

渔获种类 Species	网目结构 Mesh construction	参数 Parameters	网目尺寸 /mm Mesh size $\overline{X}\pm$SD 30	35	40	与网目尺寸的线性关系 Linear relationship with mesh sizes
哈氏仿对虾 *Parapenaeopsis hardwickii*	菱形 Diamond	L_{50}	52.17±1.32	69.37±1.6	85.94±3.06	L_{50}=3.39×M_e−48.80
		SR	30.16±3.11	35.30±3.63	40.25±4.14	SR=1.01×M_e
	方形 Square	L_{50}	64.62±1.16	79.27±2.10	93.38±3.45	L_{50}=2.88×M_e−21.37
		SR	18.69±1.92	21.87±2.55	24.94±2.57	SR=0.63×M_e
	转向 T90	L_{50}	60.31±1.64	–	96.86±6.04	L_{50}=3.66×M_e−48. 98
		SR	22.15±3.58	–	29.55±4.77	SR=0.74×M_e
葛氏长臂虾 *Palaemon gravieri*	菱形 Diamond	L_{50}	49.86±1.58	65.76±2.17	81.07±3.93	L_{50}=3.13×M_e−43.45
		SR	16.40±2.48	19.20±2.90	21.89±3.31	SR=0.55×M_e
	方形 Square	L_{50}	55.78±1.52	70.32±2.72	84.32±4.58	L_{50}=2.86×M_e−29.54
		SR	13.65±2.35	15.98±2.76	18.22±3.14	SR=0.45×M_e
	转向 T90	L_{50}	57.50±2.11	–	88.64±8.10	L_{50}=3.11×M_e−35.60
		SR	19.15±4.42	–	25.55±5.90	SR=0.64×M_e

注：M_e– 网目尺寸，mm；L_{50}– 网囊选择性参数；SR 网囊选择范围 .

Note: M_e mesh size, mm; L_{50} selectivity parameter; SR selectivity range.

对于葛氏长臂虾，各网目尺寸的方形网目网囊的 L_{50} 显著大于相应网目尺寸菱形网目网囊的 L_{50}（平均相差 7.60%，P=0.027），而选择范围 SR 显著小于菱形网目网囊（平均相差 1.68%，差异显著，P=0.007）；转向网目网囊的 L_{50} 显著大于菱形网目网囊（平均相差 12.33%，P=0.003），而 SR 也较菱形网目网囊大 16.74%（差异不显著，P=0.090），一个可能的原因是选择性模型对渔获数据缺乏拟合性（模型拟合 P=0.030）所导致。

3 讨论

3.1 方形、菱形和转向网目网囊对虾类选择性差异的原因

一般认为,方形网目网囊较传统菱形网目张开更大,使得进入网囊的渔获对象更容易穿越网目逃逸,表现在选择性方面就是方形网目网囊具有较大 L_{50} 的和较小的 SR[12,21−22]。但是也有研究,通过增大网目扩张来改善网囊对渔获种类选择性还取决于渔获个体的逃逸机制及网囊和渔获个体体型之间的匹配[23],例如,相比菱形网目,方形网目网囊对扁平鱼类的 L_{50} 较小[24]。Hannah 等[25]通过水下摄像机对长额虾(*Pandalus jordani*)在网具内的逃逸行为进行观察,发现在网囊中,虾类的逃逸行为是被动的、无方向性的,个体在接触张开的网目后其尾部先从网目中伸出,在网衣材料抖动、鱼类接触等刺激下,迅速收缩尾部,作出逃逸行为,这说明虾类头胸甲后缘的体周是决定尺寸选择性的关键因素,而不是虾类的曲体短径[2],而虾类头胸甲后缘的截面形状近似圆形,因此,方形网目网囊应较菱形网目更适合虾类的逃逸,这与试验结果是符合的。

从试验结果来看,转向网目网囊比传统菱形网目网囊更具选择性。一般来说,传统的网衣制作工艺使得结节对网衣的横向扩张方面具有一定的抵抗力,转向 90°使用后网衣在横向更容易张开,有利于渔获个体的逃逸[15],试验结果也基本证实了这一点。但是值得注意的是,渔获量大小是影响网囊选择性的一个因素[26−27],相比方形网目,转向网目网囊受这一因素的影响可能更大(网目在一定的拉力下闭合),这可能是导致 30 mm 转向网目网囊 L_{50} 比方形网目网囊小、而 40 mm 转向网目网囊 L_{50} 比方形网目网囊大的原因。不可忽略的是,在制作转向网目网囊时,为保证网囊在作业过程中主尺度与菱形网目网囊一致,转向网目网囊的周向目数被减少 15%~20%,而纵向增加 15%~20%;国外的研究结果表明,减少网囊周向长度也可以改善网囊的选择性[7,15,21];因此,对于转向网目对捕虾桁拖网网囊选择性的影响,需要进一步的试验来证实。

3.2 与前期研究结果的比较

对比孙满昌等[4]的研究结果发现,本实验中 40 mm 网目尺寸的菱形网目网囊对 2 种虾类的 L_{50} 相对较大。产生这一差异的原因可能是 2 次试验的作业季节不同,虾类个体的体型存在差异。孙满昌等[4]试验时间在 6、7 月(现已成为桁拖网夏季伏休期),这一季节正值哈氏仿对虾和葛氏长臂虾的繁殖高峰期[28],虾类个体较大,而且体型比较饱满,根据前面所述虾类个体从网囊网目逃逸的行为习性,个体穿越网目的可能性要小于非繁殖期的虾类个体,因此 L_{50} 较小;另一方面,孙满昌等[4]采用了套网法的选择性试验方法,且采用了 25 mm 网目尺寸的套网网目尺寸,相比本实验采用的对比作业法,套网的安装会产生"覆盖效应"等不利影响[29],阻碍了进入网囊的虾类个体逃逸行为,使得选择性参数 L_{50} 随网目尺寸的变化率相对较低;从试验结果来看,本实验估算的菱形网目网囊 L_{50} 与网目尺寸的线性关系(表 6)中,斜率明显大于前期的研究结果。笔者认为,孙满昌等[4]使用套网法所得结果存在一定偏差,例如菱形网目网囊对哈氏仿对虾的 L_{50} 与网目尺寸的线性关系为 L_{50}=41.47+0.87×M_e(M_e 表示网目尺寸),如果这一线性关系成立,那么套网的选择性能就不能忽视,25 mm 网目尺寸的套网对哈氏仿对虾的 L_{50} 为 63 mm,因此假设其没有选择性的假设势必会影响到选择性分析。

本实验中菱形网目网囊对虾类的选择范围 SR 要明显小于孙满昌等[4]的研究结果。这也可能是由于 2 次试验不同的试验方法所致,通常套网法所获得的 SR 要小于对比作业发根据[29]。

3.3 方形网目、转向网目在种类选择性研究方面的意义

通过改变网囊网目结构改善捕虾拖网渔具的尺寸选择性是很多捕虾拖网渔业中使用的技术手段[22,30];但是对于很多捕虾拖网渔业来说,由于目标种类个体较小,因此网囊网目也较小,渔业通常面临的是其他种类的兼捕和抛弃问题,仅通过改变网囊网目结构及网目尺寸等手段难以实现渔具选择性捕捞的目标,这种情况下,需要进行捕虾拖网渔具种类选择性研究。以东海近海捕虾桁拖网渔业为例,根据试验结果,网目内径 35 mm 的方形网目网囊对于虾类可以实现"捕大留小"选择性捕捞目标;然而,近年来由于近海渔业资源的变动,桁拖网渔具的捕捞对象从原来以虾类为主逐渐变化为虾、蟹、鱼混捕,不同作业季节主捕不同渔获对象的现象,例如在吕泗渔场秋冬汛主要捕捞三疣梭子蟹(*Portunus trituberculatus*)等蟹类资源,从拖网对主

要鱼类的选择性分析结果来看[31]，35 mm 网目尺寸的网囊对多数鱼类的选择性并不好，通过控制网囊网目尺寸以完全实现桁拖网渔业选择性捕捞的目的是不现实的，这无疑给今后渔业的管理带来了新的难题。即便如此，网目结构对网囊选择性影响的研究仍然具有重要的意义，例如在国外很多捕虾拖网渔业的选择性研究中，复合型网囊结构[30]（由不同网目结构的网片构成）、方形网目逃逸窗口[32]等设计都需要方形网目尺寸选择性信息；而在分隔式、分层式拖网中，各网囊的捕捞对象不同，改变个别网囊的网目结构以进一步优化渔具的选择性具有很广泛的运用前景，这不仅是本研究的重要意义，也为今后桁拖网渔具选择性研究提供了方向。

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Size selectivity of codends with different mesh configuration for shrimps in Chinese beam trawl fishery

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Abstract: In order to improve size selection for shrimps of multi-codends beam trawls fishing in offshore of the East China Sea，experiments of several sea trials for size selectivity of codends with different mesh configuration，including diamond mesh，square mesh and turned through 90° mesh，have been carried out and catch data were collected by comparative fishing method. In analysis of selectivity，the selectivity curves (Richards curves，which could be simplified to Logistic curves by hypothesis test theory) were considered geometrically similar and maximum likelihood method was used as the method of estimation of model parameters. The result demonstrated that selectivity models fit well to the pooled catch data of *Parapenaeopsis hardwickii*，*Palaemon gravieri* but between-trials variation was found，and Richards selectivity curves of codends with different mesh configuration could be simplified. The 50% retention lengths (L_{50}) of square mesh and T90 mesh codends for *Parapenaeopsis hardwickii* were larger than and the selectivity ranges (SR) were less than those of diamond mesh codends respectively. As for *Palaemon gravieri*，the L_{50} of square mesh and T90 mesh codends were larger than those diamond mesh codends. Difference in selectivity parameters between diamond and square mesh codends was significant while difference between diamond mesh and T90 codends was insignificant. Based on the escape behavior of shrimp in codends，the reason for the fact that square mesh and T90 codends were more selective for shrimps than traditional diamond mesh codends might be the better mesh openness of square mesh and T90 mesh. The suggestion is that the information of size selectivity of different mesh configuration was also crucial for research on species selection of beam trawls.[Journal of Fishery Sciences of China，2008，15 (4)：667-676]

Key words: size selectivity; multi-condends beam trawl; *Parapenaeopsis hardwickii*; *Palaemon gravieri*; diamond mesh; square mesh; turned through 90° mesh (T90)

第15卷第4期
2008年7月
中国水产科学
Journal of Fishery Sciences of China
Vol.15 No.4
July 2008

Optimum dosage of KCl for spawning induction and the effects of water temperature and salinity on embryonic and larval development in *Asterias amurensis*

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Abstract: The basic information of reproductive biology is necessary for the effective control of starfish in mariculture areas. In the present study, spawning induction of 0.5 mol/L KCl at various dosages (0 mL, 1.0 mL, 3.0 mL, 5.0 mL and 7.0 mL), and the effects of water temperature and salinity on embryonic and larval rearing were investigated in starfish *Asterias amurensis*. The optimum dosage group of 0.5 mol/L KCl on spawning induction was assessed to be 3.0 mL injection group, with a maximum total percentage of spawning (80%) and spawning quantity of per female 536.5×10^4 eggs, as well as a high fertilization rate $(92.7\pm2.9)\%$. The developmental rate of each stage increased with increasing of water temperature, and the suitable range of water temperature for the embryonic and larval development was 15–20 ℃, and the optimum temperature was 20 ℃ . The salinity range of 30–35, especially 35, was suitable for larval survival, development and growth.[Journal of Fishery Sciences of China, 2008, 15(4): 677–682]

Key words: *Asterias amurensis*; spawning induction; embryonic and larval development; KCl; water temperature; salinity

CLC number: Q178 **Document code:** A **Article ID:** 1005–8737–(2008)04–0677–06

It is well known that starfish is the main enemy of economic bivalve in aquaculture. For the effective control of starfish in mariculture areas, the basic information on its reproductive biology is necessary, which also can be used to culture starfish larvae to perform further experiments. In previous studies, it has been reported on the artificial fertilization, larval growth, ingestion of ultraplankton and large-scale culture in several starfishes [1-4].

Asterias amurensis, subjected to Echinodermata, Asteroidea, is a familiar species in the sea areas of Korea and China. Kim [5] observed the histological change of its gonad, and Yu et al. [6] investigated temperature effects on its early development. However, the spawning induction and effects of environmental factors on embryonic and larval rearing have not been studied in this species perfectly.

As a part of a broad project to completely understand the propagation and development of *A. amurensis*, and further develop a protocol for controlling this harmful species in aquaculture, in this study, spawning induction of KCl and the effects of water temperature and salinity on its embryonic and larval rearing were investigated.

1 Materials and methods

1.1 Materials

The optimum reproductive season for *A. amurensis* was at 5-6 months in a year. During the reproductive season, adult starfishes (body length: 15.7–16.3 cm, arm length: 8.5–8.9 cm, body weight: 96.1–99.9 g) were collected from Yeosu city, Korea and maintained in the circulating aquaria at (15 ± 1) ℃ in laboratory for a few days before experiment. During the reproductive season, the average water temperature is 17.3 ℃ in Yeosu coastal waters; The

Received date: 2007-08-28; **Revised date:** 2008-01-28.

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average salinity is 35, and salinities range from 18 to 38 in Yeosu coastal waters due the effects of runoff from land, rainfall and evaporation.

1.2 Spawning induction

Five dosages (0 mL, 1.0 mL, 3.0 mL, 5.0 mL and 7.0 mL) of 0.5 mol/L KCl were respectively injected into coelome at the base of arm to induce spawning. Ten starfish were employed in each group, and triplicates were conducted for each treatment. After the starfish spawning, the percentage of spawning individuals and spawning quantity per female were counted, and meanwhile the eggs were fertilized with sperm obtained from the males of the same injected group. The fertilization rates were calculated according to the appearance of 2-cell stage. The fertilized eggs obtained from 3.0 mL injected group were reared in tank at a density of 1 egg/mL to perform the following experiment.

1.3 Effects of water temperature and salinity on embryonic and larval rearing

To estimate the effect of water temperature on embryonic and larval development, the fertilized eggs described above were reared at salinity 35 and six temperature groups (5 ℃, 10 ℃, 15 ℃, 20 ℃, 25 ℃ and 30 ℃) respectively, and temperature was controlled by automatic heating controller. Otherwise, in salinity groups, five salinity grads which were 20, 25, 30, 35 and 40 obtained by diluting filtered natural seawater with distilled water or adding sea salt, were designed and rearing were maintained at 15 ℃. Four thousand eggs per tank were used and triplicates were conducted for every group. During the experiment, 100 random samples were collected in each group termly to determine and count the developmental stages (2-cell, 8-cell, morula, blastula, gastrula and bipinnaria) (Fig. 1), the developmental rates (mean time required to each developmental stage from zygotes for all individuals) and the survival rates under the microscope. Filtered seawater was renewed by 2/3 every day and larvae were fed with *Dunaliella tertioklecta*, *D. primolecta* and *Phaeodactylum tricornutum* daily at a density of 2×10^4–5×10^5 cells/mL during larval rearing.

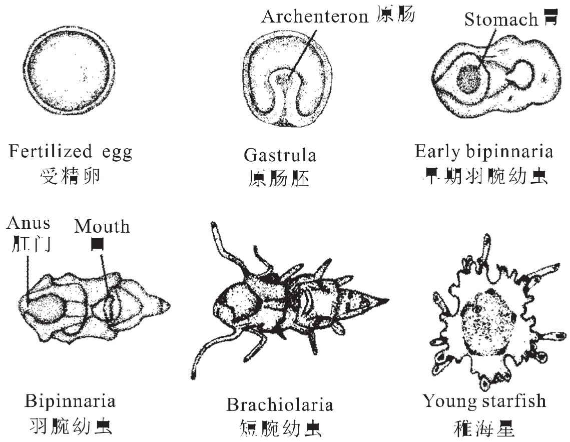

Fig. 1 Developmental stages of *A. amurensis*

图 1 多棘海盘车的发育分期

2 Results

2.1 Effect of various dosages of 0.5 mol/L KCl on spawning induction

The effect of various dosages of 0.5 mol/L KCl on spawning induction was assessed in terms of percentage of spawning starfish (Tab. 1), spawning quantity per female and fertilization rates (Tab. 2). The maximum total percentage of spawning (80%) and spawning quantity per female 536.5×10^4 eggs was found in 3.0 mL injection group, accompanied with a high fertilization rate (92.7±2.9)%. All the other groups spawned less eggs, especially the 7.0 mL group (138.6×10^4 eggs/spawning female), which also had a low fertilization rate (76.3±6.5)%.

2.2 Effect of water temperature on embryonic and larval rearing

The survival rates of embryos and larvae at different water temperatures were showed in Fig. 2. It indicated that the embryos and larvae could not develop normally at 5 ℃, 25 ℃ and 30 ℃. In 10 ℃, 15 ℃ and 20 ℃ groups, developmental rates reaching every stage became faster at 15 ℃ and 20 ℃ than at 10 ℃ (Tab. 3), and the survival rate of 10 ℃ group at each stage was also lower obviously than that of 15 ℃ and 20 ℃ groups. Figure 3 also showed that the developmental rate of each stage was increased with increasing water temperature, and the relationship between them at each stage of embryonic development was notable. Therefore the suitable range of water temperature for the embryonic development was 15–20 ℃, and the optimal temperature for survival, development and growth was 20 ℃ .

Tab. 1 Percentage of spawning *A. amurensis* induced with various dosages of 0.5 mol/L KCl
表 1 不同剂量 0.5 mol/L KCl 诱导多棘海盘车排放生殖细胞的个体百分比

KCl Dosage/mL KCl 剂量	No. of specimens 个体总数	No. of spawning 排放个体数 Female 雌	 Male 雄	Percentage of spawning /% 排放个体的百分比
0	30	0	0	0
1.0	30	15	6	70
3.0	30	15	9	80
5.0	30	15	6	70
7.0	30	9	9	60

Tab. 2 Spawning quantity per female and fertilization rates of *A. amurensis* induced with various dosages of 0.5 mol/L KCl
表 2 不同剂量 0.5 mol/L KCl 诱导多棘海盘车的排卵量和受精率 $\overline{X}$±SD

KCl Dosage /mL KCl 剂量 /mL	Spawning quantity /ten thousand 排卵量 / 万粒	Average fertilization rate/% 平均受精率
0	0	0
1.0	192–260 (213.6 ± 51.7)	94.5 ± 2.3
3.0	429–621 (536.5 ± 78.9)	92.7 ± 2.9
5.0	233.9–385.4 (276.8 ± 63.3)	91.3 ± 2.7
7.0	125.8–154.7 (138.6 ± 14.8)	76.3 ± 6.5

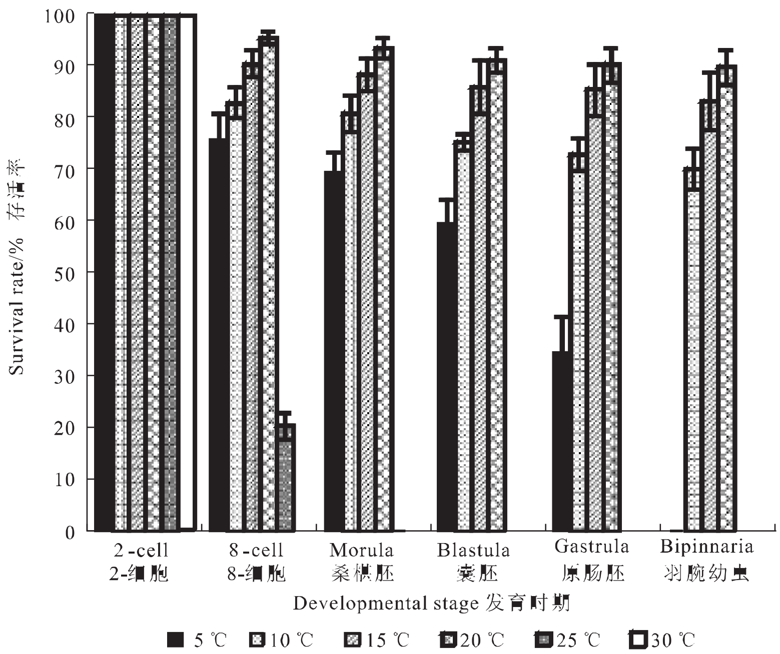

Fig. 2 Survival rates of different developmental stages at various water temperatures in *A. amurensis*

图 2 多棘海盘车各发育时期在不同水温下的存活率

Tab. 3 Time required from fertilized egg to each developmental stage at various water temperature in *A. amurensis*

表 3 不同水温下多棘海盘车受精卵发育至各时期所需时间 $\overline{X}\pm$SD; h

Developmental stage 发育时期	Water temperature /℃ 水温				
	5	10	15	20	25
2-Cell 2- 细胞	9.8 ± 0.9	3.8 ± 0.5	0.9 ± 0.2	0.6 ± 0.1	0.3 ± 0.1
8-Cell 8- 细胞	17 ± 1.2	7.7 ± 0.6	2.3 ± 0.3	1.4 ± 0.3	–
Morula 桑椹胚	42 ± 3.6	13.1 ± 1.6	3.8 ± 0.8	3.85 ± 0.7	–
Blastula 囊胚	58 ± 7.7	24.5 ± 2.1	13.1 ± 1.1	13.3 ± 1.2	–
Gastrula 原肠胚	114.9 ± 11.5	42 ± 5.6	24.8 ± 2.6	22.7 ± 2.3	–
Bipinnaria 羽腕幼虫	–	72.1 ± 6.6	53.8 ± 3.8	51 ± 4.1	–

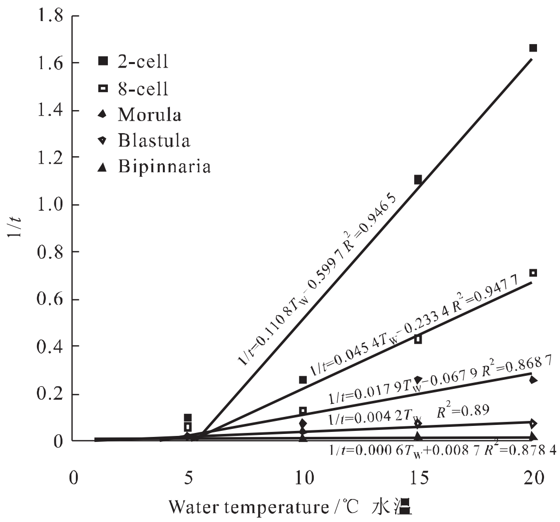

Fig. 3 Relationship between water temperature (T_w) and time (t, h) required to each developmental stage after fertilization

图 3 水温(T_w)和受精卵发育至各时期所需时间(t, h)的关系

2.3 Effect of salinity on embryonic and larval rearing

The survival rates of embryos and larvae at different salinity were showed in Fig. 4. The bipinnaria only survived at salinities 30 and 35 groups, and the difference of developmental rates at each developmental stage (Tab. 4) between 30 and 35 was not distinct. Therefore the salinity range of 30 ~35, especially 35, was suitable for larval survival, development and growth.

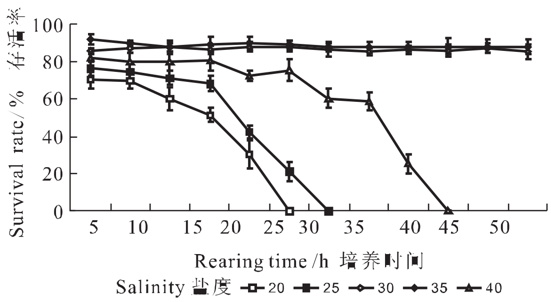

Fig. 4 Survival rates of embryos and larvae at different salinity in *A. amurensis*

图 4 多棘海盘车胚胎和幼虫在不同盐度下的存活率

Tab. 4 Time required from fertilized egg to each developmental stage at different salinity in *A. amurensis*
表 4 不同盐度下多棘海盘车受精卵发育至各时期所需时间 $\overline{X}$±SD; h

Developmental stage 发育时期	Salinity 盐度				
	20	25	30	35	40
2-Cell 2-细胞	3.9 ± 0.8	3.5 ± 0.5	1.0 ± 0.3	0.9 ± 0.2	2.81 ± 1.2
8-Cell 8-细胞	7.6 ± 1.5	7.1 ± 1.0	2.5 ± 0.7	2.4 ± 0.5	5.5 ± 2.4
Morula 桑椹胚	–	13.2 ± 2.1	4.0 ± 0.6	3.9 ± 0.6	9.5 ± 3.8
Blastula 囊胚	–	–	13.4 ± 1.1	13.2 ± 1.2	–
Gastrula 原肠胚	–	–	25.9 ± 3.2	24.9 ± 2.7	–
Bipinnaria 羽腕幼虫	–	–	55.4 ± 4.9	52.7 ± 4.4	–

3 Discussion

Although eggs obtained by dissection of gonad can also be fertilized artificially, spawned eggs by nature or induction are better for fertilization because fewer immature eggs are shed [3]. The injection of 10^{-3} mol/L 1-methyl-adenine is often used to induce the spawning of starfish and oocyte maturation [3,7–8]. However, KCl, which is used in spawning induction of sea urchin [9], is more common and cheaper and is testified that 0.5 mol/L KCl could induce spawning of *A. amurensis* in this study. The maximum total percentage of spawning (80%) and number of eggs per spawning female (536.5×10^4 eggs/spawning female) were found in 3.0 mL injection group with a high fertilization rate (92.7±2.9)%, and numbers of eggs per spawning in 1.0 and 5.0 ml injection groups were approximate half of the former, although the difference in percentage of spawning female and fertilization rate between them was not significant. In contrast, the spawning performance of 7.0 ml injection group was worse obviously. So the injection of 3.0 ml is the optimum dosage of 0.5 mol/L KCl to induce the spawning of *A. amurensis.*

Water temperature is thought as one of critical environmental factors in the embryonic and larval development of marine invertebrates. The results in this paper showed the influence of water temperature on development of *A. amurensis* was obvious. At 30 and 25 ℃, the fertilized eggs could not perform the first and third cleavage, and the bipinnaria could not survive at 5 ℃. The suitable range of water temperature for the embryonic and larval development was 15–20 ℃, and the optimal temperature for survival, development and growth was 20 ℃, which is similar with the results of Yu et al. [6].

The effect of salinity on development and growth of starfish is seldom studied. Sarantchova [10] tested the adaptive responses to salinity changes in sea starfish *Asterias rubens* L. at different ontogenetic stages and showed the narrow limits of tolerance for salinity at initial ontogenetic stages of the starfish, such as the stage of fertilized egg and the gastrula. However, this characteristic of tolerance for salinity was not observed in this study. The survival range of salinity for bipinnaria was 30–35, but that of morula was 25–40, although the developmental rates in 25 and 40 groups were obviously lower. Therefore the suitable range of salinity was 30–35, and 35 was the optimum salinity for larval survival, development and growth of *A. amurensis.*

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多棘海盘车诱导排卵最佳 KCl 剂量以及水温和盐度对胚胎和幼虫发育的影响

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摘要: 海星的大量繁殖与入侵可对滩涂养殖贝类造成极大威胁。对海星繁殖生物学的研究可为有效控制海星过度增殖提供信息,同时也可为其胚胎和幼虫培育以及发育生物学的深入研究奠定基础。本研究以韩国和中国沿海常见的多棘海盘车(*Asterias amurensis*)为材料,研究 KCl 诱导海盘车排放生殖细胞的最佳剂量,以及水温和盐度对胚胎和幼虫发育的影响。采用不同剂量 (1.0 mL、3.0 mL、5.0 mL 和 7.0 mL) 0.5 mol/L KCl 注入性成熟海盘车体腔,皆可诱导生殖细胞的排放,3 mL 注射组的排放个体比例最高 (80%),雌性个体排卵量最大 (536.5×10^4 个 /ind),同时用诱导获得的精 / 卵进行人工授精后也获得了较高的受精率 (92.7±2.9)%。水温和盐度对多棘海盘车胚胎和幼虫的存活率具有显著的影响。在盐度为 35 时,20 ℃时多棘海盘车羽腕幼虫的存活率最高 (90.1±2.1)%,15 ℃时次之 (84.4±5.2)%。在温度为 15 ℃时,盐度为 35 时幼虫培养 60 h 后存活率最高 (87.6±4.1)%,盐度为 30 时次之 (85.4±4.0)%。多棘海盘车各期胚胎和幼虫的发育速度 ($1/t$, h^{-1}) 随水温升高而加快,在一定温度范围内有明显的正相关性,其关系式为:至 2- 细胞:$1/t=0.110\,8T_w-0.599\,7$ ($r^2=0.946\,5$);至 8- 细胞:$1/t=0.045\,4T_w-0.233\,4$ ($r^2=0.947\,7$);至桑椹胚:$1/t=0.017\,9T_w-0.067\,9$ ($r^2=0.868\,7$);至囊胚:$1/t=0.004\,2T_w$ ($r^2=0.89$);至羽腕幼虫:$1/t=0.000\,6T_w-0.008\,7$ ($r^2=0.878\,4$)。盐度为 35 时,胚胎和幼虫的发育速度最快,发育至羽腕幼虫需 55.4 h。根据不同水温和盐度条件下,胚胎和幼虫的存活率和发育速率,确定 15~20 ℃是多棘海盘车发育的适宜温度,最适温度为 20 ℃;适宜盐度为 30~35,最适盐度为 35。[中国水产科学,2008,15(4):677-682]

关键词: 多棘海盘车;排卵诱导;胚胎和幼虫发育;KCl;水温;盐度