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鱼类“致癌、致畸、致突变”测试技术在渔业环境监测中的应用*

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摘 要 以毒理学为指导，现代医学测试技术为基础，研制出适合鱼类“致癌、致畸、致突变”的测试技术和方法，并将之应用于渔业环境监测。对长江下游的南京段和镇江段监测表明，两江段受测鱼均发生不同程度的致畸、致突变效应，说明其水域中存在诱变源，且与该水域石油含量过高有关；对无锡河段泥鳅的致癌测试结果表明，该河段的泥鳅肝脏已发生恶性肿瘤，即肝癌。

关键词 鱼类，致癌，致畸，致突变，环境监测

未经处理的工业、生活废水排入江河湖泊，给水域环境和鱼类带来危害。具有诱变性的污染物还能导致鱼类“致癌、致畸、致突变”效应[1~3]1)，并使鱼类的遗传物质及种质发生改变。目前尚无成熟的、切实可行的测试技术，我们经十多年的努力，研制出一套适合渔业环境监测的“三致”测试技术，并将之成功运用于实际监测工作中。

1 材料和方法

1.1 鱼体样品来源

鱼体样品，捕自长江下游的南京和镇江江段指定区域；泥鳅来自于无锡市内河道。

1.2 染色体畸变的检验

1.2.1 染色体畸变检验–离体培养试验（in vitro）

将南京、镇江两江段鱼样外周血接种于1640培养基中，在28～30℃条件下培养72 h，接着按0.1～0.2 μg/ml培养液的剂量注入秋水仙素，继续培养3.5 h左右，然后进行低渗、固定、制片、染色和镜检分析。

1.2.2 染色体畸变检验–整体培养试验（in vivo）

将南京、镇江两江段鱼样按体重3～5 μg/g的剂量注入秋水仙素，培养6 h左右，取出鱼肾组织制成肾悬浮液，进行离心、低渗、固定、制片、染色和镜检分析。

1.3 鱼类外周血微核检验

将南京、镇江两江段鱼样现场断尾取血，制成涂片，立即用甲醇固定，Giemsa染色，回实验室后镜检分析。

1.4 鱼类生殖毒性检验

将两江段的污染水样（主要指污染带水样）取回后，在实验室条件下通过对草鱼亲鱼的人工繁殖测试，观察受精率、孵化率、畸形率和成活率，结果可用来表示两江段污染带水质对鱼类的生殖毒性和致畸作用。

1.5 鱼类癌变检验

观察泥鳅活体，从外表可看到部分肿瘤性病变，但通常难以观察到内脏的异常，需进行病变检查。将其解剖各器官用10%的福尔马林固定，然后进行组织切片检验。

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* 本文为农业部重点项目《鱼类“致癌、致畸、致突变”测试技术在渔业环境监测中应用的研究》的主要内容，该项目于1996年获农业部科技进步三等奖，项目编号：8512 04。

1）张瑞涛，陈家长，等．病毒诱发泥鳅肝癌的调查研究．渔业环境保护，1996

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2 结果

2.1 鱼类致突变的监测结果

对长江下游南京、镇江两江段的鱼类实地监测结果[2,4,5]见表1、表2。

表 1 长江下游两江段鱼类染色体结构畸变测定结果

Table 1 Chromosomal mutation of fishes in 2 lower sections of the Changjiang River

江 段 river section	种 类 species	染色体的细胞数/个 cell no.	染色体畸变细胞数/个 cell no. of chromosomal mutagenicity	细胞畸变率/% cell mutagenicity rate	染色体的总数/个 no. of chromosome	染色体畸变的总数/个 no. of chromosomal mutagenicity	染色体畸变率/% chromosomal mutagenicity rate
南 京 Nanjing	鲤 *Cyprinus carpio*	200	13	6.5	200×100	202	1.01
	草鱼 *Ctenopharyngodon idellus*	200	9	4.8	200×48	118	1.23
	圆口铜鱼 *Coreius guichenoti*	200	8	4.0	200×50	101	1.01
	长吻鮠 *Leiocassis longirostris*	200	14	6.8	200×52	182	1.75
	鳙 *Aristichthys nobilis*	200	6	3.2	200×48	106	1.10
镇 江 Zhenjiang	鲤 *Cyprinus carpio*	200	14	7.0	200×100	231	1.15
	鳗鱼 *Anguilla japonicus*	200	22	11.2	200×38	144	1.89
	长吻鮠 *Leiocassis longirostris*	200	25	12.5	200×52	192	1.84
	圆口铜鱼 *Coreius guichenoti*	200	11	5.5	200×50	118	1.18

表 2 长江下游两江段鱼类微核测定结果

Table 2 Fish micronucleus in 2 sections of the Changjiang down stream

江 段 river section	种 类 species	嗜多染红细胞数/个 no. of analyzed polychromatocyte	微核细胞率/‰ rate of cell micronucleus	细胞微核率/‰ rate of cell micronucleus	标准正常值/‰ reference criteria	微核细胞率相当于正常值的系数 ratio of micronucleus cell rate equivalent to nomal value
南 京 Nanjing	鲤 *Cyprinus carpio*	500	4.32 + 0.23	8.2 ± 0.36	0.2	21.60
	草鱼 *Ctenopharyngodon idellus*	500	2.55 ± 0.31	3.5 ± 0.21	0.2	12.75
	铜鱼 *Coreius heterodon*	500	3.60 ± 0.44	7.6 ± 0.33	0.2	18.00
	鳙 *Aristichthys nobilis*	500	3.30 ± 0.38	5.8 ± 0.19	0.2	16.50
镇 江 Zhenjiang	鳗鱼 Anguilla japonica	500	5.56 ± 0.33	10.8 ± 0.47	0.2	28.30
	鲤 *Cyrinus carpio*	500	4.20 + 0.43	11.3 ± 0.43	0.2	21.00
	鳙 *Aristichthys nobilis*	500	3.40 ± 0.27	7.8 ± 0.28	0.2	17.20
	草鱼 *Ctenopharyngodon idellus*	500	4.42 + 0.38	4.4 ± 0.17	0.2	22.10

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南京段鱼类染色体细胞畸变率为 3.2% ~ 6.8%,染色体结构畸变率为 1.01% ~ 1.75%,微核细胞率为 2.55‰ ~ 4.32‰,细胞微核率为 3.5‰ ~ 8.2‰,畸变率最高的为草鱼和长吻鮠;镇江段鱼类染色体细胞畸变率为 5.5% ~ 12.5%,染色体结构畸变率为 1.15% ~ 1.89%,微核细胞率为 3.40‰ ~ 5.60‰,细胞微核率为 4.4% ~ 10.8%,畸变率最高的为鳗鱼和长吻鮠。

2.2　鱼类生殖毒性的监测结果[3,5,10]

南京江段炼油厂排江口下游水质对草鱼几项测定指标的影响分别为:受精率下降 19%,孵化率下降 77%,成活率下降 257%,畸形率比对照组高 51%;镇江江段 3 号码头对草鱼的几项测定结果为:受精率下降 34%,孵化率下降 70%,成活率下降 193%,畸形率比对照组高 67%(表 3)。

表 3　长江下游两江段污染水域鱼类生殖毒性和致畸的测试结果

Table 3　Effects of polluted water on fish propagation and malformation in 2 lower sections of the Changjiang River

取样江段 river section	测试鱼类 samples	观测指标 observation index				备注 remarks
		受精率/% fertilization rate	孵化率/% hatching rate	畸形率/% malformation rate	成活率/% survival rate	
南京炼油厂排江口下游 lower stream of drainage	草鱼 *Ctenopharyngodon idellus*	72	44	51	23	石油含量/mg·L^{-1} oil 0.41
镇江江段 3 号码头 Zhenjiang section	草鱼 *Ctenopharyngodon idellus*	64	46	67	28	石油含量/mg·L^{-1} oil 0.47
对照组 control group	草鱼 *Ctenopharyngodon idellus*	86	78	0	82	

2.3　鱼类致癌性的监测结果[7~9]

对无锡市内重污染河段(主要为有机污染)的泥鳅进行现场观察分析,其外部形态症状为:体型异常消瘦,机体腹部隆起畸形,肠内少有食物,游动异常迟缓;解剖症状特点为:肝脏肿大,肝体变成浅黑色,肝脏外观出现致密的灰白色斑点。这可能与水环境中病源微生物有关,尤其与病毒感染有关,具体检测结果见表 4。

表 4　泥鳅的检测结果

Table 4　Analytical results of *Misgurnus anguillicautus*

断面 section	样品数 samples	平均体长/cm mean length	平均体重/g mean weight	平均肝体重/g liver weight	肝、体重比 liver/body	对照的肝体重比 control
I	218	14.8	15.4	0.53	1:29.1	
II	141	18.6	21.3	0.69	1:30.9	1:75.2
III	173	15.6	17.8	0.57	1:31.2	

对泥鳅进行饲养恢复试验,饲养 30 d 后,测定发现肝、体重比没有多大变化,肝肿大未能减轻,可以认为泥鳅的肝肿大的性质是由于肝组织增生而引发的肝肿瘤或肝癌所致[7,8]。电镜观察和图像病理分析发现其肝组织病变主要有以下症状:①细胞核和细胞浆比例失调,细胞核明显增大;②细胞核出现显著内陷和核分裂,类似形成多核细胞,且细胞核形态极不规则,表现为多态性;③细胞核染色质增粗,并出现凝聚和趋边现象;④核膜增厚,且有双层结构的介膜;⑤细胞质中的线粒体和内质网已发生明显的变异,出现凝聚型巨大线粒体,呈“C”型并包含着 1 个小线粒体;⑥细胞质内出现了致密的包含体。这表明泥鳅的肝组织细胞已成为病毒颗粒聚集的地方。

3　讨论

3.1　致突变情况

南京与镇江两江段鱼类均发生程度略有不同的染色体畸变,说明鱼类种质发生了遗传变异,尽管这种变异是漫长的,但对种质的影响,以及鱼类繁殖的影响将是非常严重的和不可忽视的。

鱼类染色体畸变和细胞微核的监测结果表明,两江段水环境不但含有诱变源,且具高浓度、强活性诱变物,水质监测结果可以认为,两江段中造成严重污染的石油类是导致鱼类染色体发生畸变的主要

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诱变物。

3.2 生殖毒性分析

通过对草鱼的生殖毒性和致畸作用分析,说明两江段污染带和重污染区水质对鱼类的生殖毒性和繁殖影响极为明显。就整个江段而言,这种情况虽然是局部的,但鱼苗在洄游途中,易误入重污染水域。这对鱼类资源的破坏是相当严重的。

3.3 致癌情况

从肝组织细胞显微结构的变异特点可以看出,污染河段泥鳅肝组织细胞的病变与癌细胞的变异症状完全相同,故可以认为该泥鳅的肝肿大实为恶性肿瘤即肝癌。从细胞质中出现的致密包含体分析,可能同病毒颗粒的感染诱发有关。

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Application of analytical technique for fish canceration, malformation and mutation in fisheries environmental monitoring

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Abstract An analytical technique for testing canceration, malformation and mutation of fishes was developed based on toxicology and modern medical analytical technology and applied to the monitoring of fishery environment. The results confirm that the fishes in the 2 river sections of Nanjing and Zhenjiang, lower reach of the Changjiang River, have got malformed and mutant due to the over-high condense of oil in the water. The monitoring results in Wuxi river section express that the malignancy (liver cancer) has been occuring in *Misgurnus anguillicautus* livers.

Key words fish, canceration, malformation, mutation, environmental monitoring

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Experimental studies on intensive polyculture of Chinese shrimp with bay scallop*

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Abstract Stocking performance, productivity and up limit carrying amount in an intensive polyculture of Cinense shrimp(*Penaeus chinensis*) with bay scallop(*Argopecten irradians*) were investigated by using 8 enclosures, each 5.0 m × 5.0 m × 1.8 m, fitted in a closed 1.7 hm^2 seawater pond in 1996. The Chinese shrimp and juvenile bay scallop were bred mixed in the enclosures at a density of 6.0 shrimp/m^2 and 0, 1.5, 4.5 and 7.5 scallop/m^2, respectively, and reared with commercial feed, chicken manure and chemical fertilizer. There was no significant difference in survival rate of Chinese shrimp between 0 and 1.5 scallop/m^2; the mean final body length, body weight and yield of shrimp decreased with the increasing of stocking density of bay scallop significantly($P<0.05$). The yield of the bay scallop incresaed from 470 kg/hm^2 at 1.5 scallop/m^2 to 1 236 kg/hm^2 at 7.5 scallop/m^2. However, the percentage of wet soft tissue weight in total wet weight decreased from (42.84 ± 3.44)% at low scallop density to (37.88 ± 4.26) % at high scallop density. The results indicate that the up limit carrying amount of scallop is 600～800 kg/hm^2 and the optimum stocking density of scallop is 1.0 scallop/m^2.

Key words Chinese shrimp, stocking, bay scallop, shrimp culture, polyculture, enclosure

Filter - feeding molluscs have been widely reared in polyculture due to their plentiful supply of juvenile, good growth, short cultural period and resistance to stresses[1～6]. Experiments on intensive polyculture of bay scallop (*Argopecten irradians*) with Chinese shrimp (*Penaeus chinensis*) have been succeeded[7～13]. However, there are few studies on optimum stocking performance, productivity and up limit carrying amount in the polyculture, and hence, by using land - based enclosures in a closed seawater pond in Shandong during May～October 1996, we completed some items above.

1 Materials and methods

1.1 Materials

Juvenile bay scallop, shell length(1.10 ± 0.12) cm, came from the Experimental Hatchery Centre for Spreading Advanced Fishery Technique in Yian Tai, Shandong. Chinese shrimp, body length(2.84 ± 0.16) cm, from Huang Hai Fisheries Company, Shandong.

The experiments were conducted in a seawater pond (1.7 hm^2, 1.8 m deep) at Huang Hai Fisheries

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Company. The water level in the pond was maintained at 1.0~1.6 m. Eight land-based enclosures, with bottom fences installed in mud of the test pond, each 5.0 m × 5.0 m × 1.8 m, were lined with ployethylene water-proof and supported by wooden posts. For the structure of the enclosures, refer to ①.

1.2 Design for experiment

The 8 enclosures were divided into 4 groups. Each group was stocked with juvenile bay scallop at a density of 0, 1.5, 4.5 and 7.5 scallop/m^2, respectively, with 150 juvenile Chinese shrimp (6.0 shrimp/m^2) in every enclosure. The scallop seeds in every enclosure were located in 4 baskets, each (height 1.2 m, mesh 0.5 cm) containing 8 layers. In each layer there were 1~6 scallop.

The Chinese shrimp were fed with commercial pellet food (45% crude protein)① at a daily dose of 10%~15% of body weight in 2 separate times (04:00~05:00 and 16:00~17:00).

After the enclosures were filled with seawater, fertilizers were added at a rate of 100g dry chicken manure and 10g urea per enclosure (N:P = 7:1). After stocking, regular fertilizing could maintain the optimum water color and transparency (35~45 cm). Chemical fertilizer (15-50-0) was primarily applied at 8 kg/hm^2 per week after the feeding began. If pH >9.0 in the afternoon, the chicken manure was applied①.

1.3 Statistical analysis

Ten Chinese shrimp were sampled by a 70 cm diameter dip net every 15 d and the individual body length (mm) was measured for mornitoring their growth over the cultural period. Ten scallop were sampled randomly and the shell length and wet weight were measured individually at intervals of one month.

The maximal mean daily net production (shrimp or scallop) measured above dinoted procuctivities and carrying capacity in a pond, and the biomass of shrimp presented the load of shrimp in a pond when their instantaneous growth rate was almost zero. The up limit carrying amount of scallop in an enclosure meant the most scallop biomass affecting the growth of the shrimp significantly.

The sizes of the shrimp and shell (length, wet body weight) were calculated with Mean ± S.D. The data were analized and tested with Variance Test and *t* Test. The result showed $\alpha = 0.05$[14].

2 Results

2.1 Comparison of cultural results between polyculture and monoculture

The Chinese shrimp were reared for over 3 months and caught with a cast net on 25 August. There was no significant difference in survival rate of shrimp between the polyculture (with 1.5 scallop/m^2) and the monoculture (Table 1). But the average body length, body weight and yield of the shrimp were 2.5%, 3.8% and 6.5% higher in polyculture than those in monoculture, respectively. The absolute conversion efficiency of nitrogen (= nitrogen contents of Chinese shrimp and bay scallop × 100/N contents in the feed and fertilizer applied) was 62.2% higher in the polyculture (17.27%) than that in the monoculture (10.65%).

2.2 Effect of stocking density of scallop on growth and survival of Chinese shrimp

The bay scallop were reared for 100 d and harvested on 3 October. The final body length, body weight and survival rate of Chinese shrimp decreased with increasing stocking density of the scallop over 1.5 scallop/m^2 (Table 1).

The yield and survival rate of the shrimp were correlated with the scallop density negatively. Statistical analysis indicated that the yield and survival rate of the shrimp were significantly different from those at 4.5 scallop/m^2. Regression equation between shrimp yields (Y, kg/hm^2) and stocking density of bay scallop (X, scallop/m^2) was expressed as follows:

$$Y = 573.33 - 41.474X \quad (r = -0.9801)$$

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① Wang Jiqiao, Li Deshang, etc. Experimental studies on polyculture in closed shrimp ponds. I. Intensive polyculture of Chinese shrimp with red Taiwainese tilapia. Aquaculture, in press

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Table 1　Final sizes, yields and survival rates of Chinese shrimp and bay scallop in their intensive polyculture (n = 60)

scallop/m^2	Chinese shrimp				bay scallop			
	BL*/cm	BW/g	yield**/g/m^2	survival**/%	SL*/cm	BW/g	yield/g/m^2	suvival/%
0	9.04 ± 0.47a	8.65 ± 1.30	49.37dbc	81.53a				
15	9.34 ± 0.50b	9.19 ± 1.28	52.57ac	83.67a	5.9 ± 0.6abc	34.3 ± 8.7	47.0	94.76
45	8.68 ± .0.54c	7.97 ± 1.50	35.76b	65.34b	4.8 ± 0.5ba	19.7 ± 5.6	87.1	88.91
75	8.68 ± 0.62c	7.76 ± 1.83	27.69ca	47.34b	5.2 ± 0.5cab	20.9 ± 5.1	123.6	85.41

Note: Data in the table is based on each treatment in the 2 enclosures. BL = body length; BW = body weight; SL = shell length; * Means with different letters differ significantly based on ANOVA and Duncan multiple range test at $\alpha = 0.05$. * * Means with diffrent letters differing significantly based on Student's t test at $\alpha = 0.05$.

2.3　Relationships between stocking density of bay scallop and their survival and yield

The final body weight of the scallop decreased with the increase of their stocking density by 39.1% ~42.6% (Table 2). The average yield of the scallop increased with the increase of scallop stocking density significantly. At 1.5 scallop/m^2, the average yield of the scallop was 470 kg/hm^2; as the stocking density increased to 6.5 scallop/m^2, the average yield increased to 1 236 kg/hm^2. As wet body weight of the scallop increased, there was a significant increase in percentage of shelled wet body weight (soft tissue weight) in total wet weight. At 7.5 scallop/m^2, the mean final body weight of the scallop was (20.9 ± 5.1) g, and the percentage of the shelled wet body weight 37.88% ± 4.26% in total body weight. At 1.5 scallop/m^2, the mean final wet body weight of the scallop was (34.3 ± 8.7)g, while the shelled wet body weight accounted for 42.84% of its total wet body weight. This indicated that there was no significant difference in yield expressed by the shelled weight because the percentage of shell weight in total wet weight also increased with the increasing of scallop's body weight.

Table 2　Condition factors at different scallop densities

scallop/m^2	body weight/g	RWST/%	condition factor/%
1.5	34.3 ± 8.7	42.84 ± 3.44ac	15.73 ± 1.39ac
4.5	19.7 ± 5.6	39.73 ± 8.03b	17.24 ± 2.49bc
7.5	20.9 ± 5.1	37.88 ± 4.26ca	14.07 ± 1.62cab

Note: Means with different letters differ significantly based on Student's t test at $\alpha = 0.05$. RWST—ratio of wet soft tissue. Condition factor(%) = wet body weight(g) × 100/shell length/cm.

2.4　Productivity of Chinese shrimp at different stocking densities of scallop

In the intensive polyculture of Chinese shrimp with bay scallop, the productivitiy of shrimp was 1.028 $g \cdot d^{-1} \cdot m^{-2}$, occuring at 15 000 scallop/hm^2 (Table 3), which was similar to that (1.11 $g \cdot d^{-1} \cdot m^{-2}$) in the intensive polyculture of Chinese shrimp with red Taiwan tilapia①. The productivity of Chinese shrimp decreased significantly when the stocking density of scallop increased.

The growth of Chinese shrimp was inhibited after the pond were stocked with bay scallop for 1 month when the scallop net yield was 0.99 $g \cdot d^{-1} \cdot m^{-2}$. The up limit carrying amount of bay scallop was 305.6 kg/hm^2 corresponding to the growth of Chinese shrimp.

Table 3　Growth rate of Chinese shrimp at different stocking densities of bay scallop in an intnsive shrimp – scallop polyculture

scallop/m^2	Time /m:d	BL/cm	BW/g	DBLI /mm	DBWI /mg	net yield/ ($g \cdot d^{-1} \cdot m^{-2}$)
0	6:25	6.34 ± 0.52a	3.12 ± 0.68	0.85	96.1	0.580
	7:10	7.15 ± 0.36a	4.42 ± 0.69	0.54	86.7	0.520
	7:25	7.93 ± 0.53db	6.02 ± 1.24	0.52	106.7	0.640
	8:12	9.04 ± 0.47dbc	8.65 ± 1.30	0.66	157.2	0.943
1.5	6:25	6.10 ± 0.49a	2.77 ± 0.67	0.76	82.2	0.493
	7:10	7.01 ± 0.42a	4.18 ± 0.76	0.61	94.0	0.564
	7:25	8.22 ± 0.53ac	6.75 ± 1.29	0.81	171.3	1.028
	8:12'	9.34 ± 0.50abc	9.19 ± 1.28	0.62	135.6	0.813
4.5	6:25	6.21 ± 0.59b	2.95 ± 0.81	0.73	83.3	0.500
	7:10	6.89 ± 0.43b	3.96 ± 0.76	0.45	67.3	0.404
	7:25	7.87 ± 0.50b	5.91 ± 1.13	0.65	130.0	0.780
	8:12	8.68 ± 0.54ba	7.97 ± 1.51	0.45	114.4	0.687
7.5	6:25	6.17 ± 0.41c	2.86 ± 0.55	0.71	79.4	0.477
	7:10	7.02 ± 0.52c	4.21 ± 0.94	0.57	90.0	0.540
	7:25	7.38 ± 1.58ca	5.33 ± 1.43	0.24	74.7	0.448
	8:12	8.68 ± 0.62ca	7.76 ± 1.83	0.72	135.0	0.810

Ntoe: Means with different letters differ significantly by Student's t test at $\alpha = 0.05$. BL = body length; BW = body weight; DBLI = daily body length increment, DBWI = daily body weight increment

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3 Discussion

3.1 Role of bay scallop in an ecosystem of shrimp polyculture

In general, organic particles approximately account for 50% of total organic matter in high fish yield ponds[15]. Being filter feeders, scallops can change water quality. The ostia of black scallop (*Chlamys varia*) (14~18 μm in diameter) are only guarded by prolaterofrontal cilia (12~15 μm long) without a screen across the ostia formed overlapping eulaterofrontal cirri. At low algal concentrations scallops show high filter effeciency for particles over 7 um in diameter. As algal concentrations increase, scallops become more efficient in retaining small (2~4 μm) particles with their abondant mucus. Also, feeding period and amount of bay scallop can vary with phytoplankton concentration[16], thus the water transparency and primary production get controlled. During the experiments, the improvement of pond environment was illustrated by the high DO level (Fig. 1) and steady transparency. It is estimated that 0.8~1.9 L of water was filtered by 1 bay scallop in 1 h[17]. It means the water in a 1 hm^2 sized and 1.0 m deep pond can be filtered once every other day by the scallop of 20 000/hm^2.

In June and July, DO levels did not differ significantly and increased with increased scallop density in the enclosure (Fig. 1). Meanwhile, the primary procuction was high in the enclosure (Fig. 2). However, in August and September, the primary production significantly declined with increase in stocking density of the scallop due to its high biomass.

3.2 Optimum stocking density of bay scallop

Li[18] described fish carrying capacity expressed by kg/hm^2 in waters as the maximum fish production within water quality criteria for drinking or fisheries according to the uses of water. The up limit carrying amount for a species of animal is referred to its biomass when its minor population inhibit the growth of the main species.

As shown in Table 3, the growth of Chinese shrimp differed slightly among the different densities of bay scallop for their small size and low biomass in the first month after the scallop were bred in pond. Since then (July 25, shell length>3.0 cm) there was a significant influence of scallop concentration on the growth of Chinese shrimp. The growth rate of Chinese shrimp was much higher at 1.5 scallop/m^2 than that at 7.5 scallop/m^2 when the net yield of bay scallop was 0.99 $g \cdot d^{-1} \cdot m^{-2}$, which suppressed the growth of Chinese shrimp obviously (Table 4). It was found that the up limit carrying amount and productivity of bay scallop were 305.6 kg/hm^2 and 2.29 $g \cdot d^{-1} \cdot m^{-2}$, repectively.

Table 4 Growth rate of bay scallop at different stocking densities in intensive shrimp - scallop polyculture

time/month:date	enclosure No.	SL/cm	BW/g	DISL/mm	DIBW/mg	yield/$g \cdot d^{-1} \cdot m^{-2}$
07:24	1	3.55±0.21	9.34±0.19	0.82	303.6	0.46
	4	3.33±0.42	7.78±0.19	0.72	251.6	0.38
	X	3.44ac	8.56ac	0.77	277.6	0.42
	2	3.18±0.19	6.76±1.38	0.69	217.6	0.98
	5	3.03±0.60	6.81±2.69	0.64	219.2	0.99
	X	2.66ca	3.58abc	0.67	218.4	0.99
	3	2.66±0.39	3.85±1.31	0.52	120.6	0.91
	6	2.66±0.30	3.21±0.86	0.52	99.2	0.75
	X	2.66ca	3.58abc	0.52	109.9	0.83
08:20	1	3.91±0.48	10.22±4.25	0.13	32.6	0.05
	4	3.71±0.57	10.21±4.16	0.14	90.0	0.13
	X	3.81a	10.22ac	0.14	61.3	0.09
	2	4.68±0.62	14.42±6.29	0.56	505.9	2.29
	5	4.13±0.45	12.63±3.17	0.41	215.6	0.97
	X	4.41bc	13.51	0.49	360.8	1.63
	3	3.09±0.29	5.20±1.43	0.16	50.0	0.38
	6	2.69±0.48	3.26±2.60	0.01	1.9	0.01
	X	2.89cb	4.23ca	0.09	25.9	0.20

Note: Means with different letters differing significantly based on Student's t test at $\alpha=0.05$.

During the first month the growth rate of scallop shell length was great (0.52~0.83 $mm \cdot d^{-1}$), which was significantly greater than that of *Thalassiosira pseudomama* in indoor troughs (1.0 $mm \cdot week^{-1}$) (Table 4). Two months later, however, the growth rate of body weight was great (200~500 $mg \cdot d^{-1}$) under suitable conditions (4.5 scallop/m^2),

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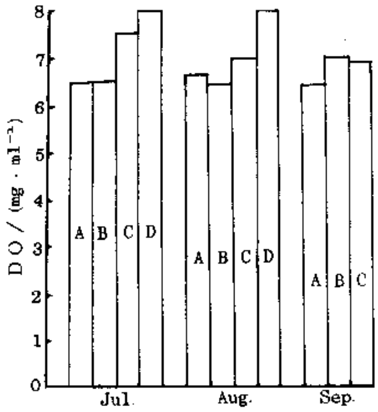

Fig. 1　DO in polyculture of Chinese shrimp with bay scallop

A, B, C and D represente the stocking density of 0, 1.5, 4.5 and 7.5 scallop/m^2, respectively.

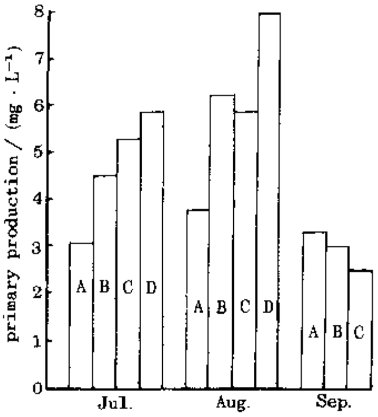

Fig. 2　Primary production in polyculture of Chinese shrimp with bay scallop

A, B, C and D represente the stocking density of 0, 1.5, 4.5 and 7.5 scallop/m^2, respectively.

which was in agreement with the fact that the growth rate of body width of old bay scallop was greater than that of young ones[19].

The growth rate of individual scallop was inversely related to the stocking density of bay scallop. However, the net yield of scallop was the highest at the median stocking density(4.5 scallop/m^2). By polyculture of Chinese shrimp with bay scallop not only water quality can be controlled, the net yield of shrimp can be increased as well. Thus the optimum stocking density of bay scallop with shell length >1.0 cm is 1.0～1.5 scallop/m^2 based on its up limit carrying amount.

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中国对虾与海湾扇贝投饵混养的实验研究

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摘　要　用放在海水池塘中的8个陆基围隔(5.0 m×5.0 m×1.8 m),研究中国对虾(*Penaeus chinensis*)与不同密度海湾扇贝(*Argopecten irradians*)投饵混养的放养方式、生产力和极限放养量。对虾体长(2.85±0.16)cm,扇贝壳长(1.10±0.12)cm,放养密度分别为6.0尾/m^2 和0,1.5,4.5,7.5粒/m^2,用投饵和施肥(鸡粪和化肥)饲养。结果表明,扇贝密度为0和1.5粒/m^2 时,对虾的成活率无显著差异。混养(扇贝1.5粒/m^2)时对虾的出塘体长、体重和产量分别比单养高2.5%,3.8%和6.5%;当扇贝密度高于1.5粒/m^2 时,对虾的平均体长、体重和产量随扇贝密度的增加而显著减少($P<0.05$)。扇贝密度为1.5和7.5粒/m^2 时,其产量由470 kg/hm^2 增至1 236 kg/hm^2;当扇贝密度高时,去壳后湿重占体重的百分数从(42.84±3.44)%降至(37.88±4.26)%。扇贝的极限放养量为600～800 kg/hm^2,适宜放养密度为1.0～1.5粒/m^2。

关键词　中国对虾,海湾扇贝,对虾养殖,混养,池塘

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