

不同盐度驯化模式对施氏鲟生长及摄食的影响

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摘要: 采用逐步增盐法(IG)、阶段增盐法(IT)及盐度突变法(IS)3种不同的驯化模式对施氏鲟(*Acipenser schrenckii*)进行盐度驯化, 对3种模式下的特定生长率(SGR)、生长效率(GE)、摄食率(FR)及食物转化率(FCR)进行统计, 并与对照组(CT)进行比较分析。结果表明, 驯化方法对于施氏鲟的成活率具有较大影响, 3种不同驯化模式下的成活率由高到低依次是IT(100%)、IS(93.33%)、IG(85%), 各盐度驯化组死亡个体规格均较小。盐度对于施氏鲟的生长具有一定的抑制作用, 盐度驯化各组在SGR、GE方面均低于对照组, IS组和IG组SGR与CT组无显著性差异($P > 0.05$), IT组显著($P > 0.05$)低于CT组。IG、IS、IT组与CT组相比, 摄食率有所下降, 但无显著差异($P > 0.05$)。IG、IT、IS各组FCR均低于对照组, 但对照组FCR与IG、IS组没有显著差异, 与IT组差异显著($P < 0.05$)。结论认为, 尽管盐度对于施氏鲟的生长具有一定的影响, 但是通过IG及IS方法的驯化, 施氏鲟在25盐度下仍然保持一定的生长速度。[中国水产科学, 2006, 13(6): 945-950]

关键词: 施氏鲟; 海水驯化; 特定生长率; 生长效率; 食物转化率

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盐度是鱼类生长发育的关键性因子之一, 对于早期受精卵的发育、卵黄营养的吸收及稚幼鱼、成鱼的生长有着极为重要的决定作用^[1]。对于一些狭盐性淡水种类, 盐度的变化对其存活及生长产生极大的影响, 若盐度超过其耐受力将导致其死亡。然而, 对于广盐性淡水种类经过适当的盐度驯化, 在一定的盐度范围内可以保持良好的生长性能^[2]。通过筛选、驯化, 将一些广盐性鱼类驯化进行海水养殖, 对于改变目前中国海水网箱养殖品种的结构、提高养殖效益等具有较高的理论意义和应用价值。

鲟科鱼类大多为洄游性鱼类, 具有较好的渗透压调节能力, 能够在海水、淡水两种不同的渗透环境中生存^[3]。施氏鲟(*Acipenser schrenckii*)是中国重要的鲟类养殖对象, 属大型河川性淡水鱼类^[4]。通过对施氏鲟的急性耐盐性研究发现, 施氏鲟属于广盐性鱼类, 对盐度具有较强的适应能力, 急性耐受盐度可以达到15左右, 经适当驯化可适应更高的盐度环境^[1]。

本研究以施氏鲟幼鱼为实验材料, 分别设计了3种不同的驯化模式, 并对驯化过程中3种不同驯化模

式下存活、生长、摄食率及食物转化率等进行比较分析, 旨在探索盐度变化对于施氏鲟生长、存活的影响, 为筛选合理的施氏鲟海水驯化模式提供技术支撑。

1 材料与方法

1.1 材料

施氏鲟为人工繁育所得, 2月龄, 体格健壮。实验开始前, 受试鱼在实验容器中暂养7 d。

实验容器为蓝色平底圆形玻璃钢桶, 直径0.85 m, 深0.70 m, 水深0.50 m, 桶底部中心有一出水口用于排污换水。

实验用水为经颗粒活性炭及KDF(Kinetic Degradation Fluxion)方法过滤(余氯低于0.01 mg/L)的自来水与浓缩海水按比例配制的不同浓度的海水。用水质分析仪(HACH YSI-ADV6600)进行校正, 海水配好静置1天后使用。

1.2 实验设计

设计淡水养殖对照组(CT)和3种不同驯化模式组: (1)逐步增盐法(IG), 盐度每天增加1个单

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1) 庄平, 赵峰, 李大鹏, 等。施氏鲟和西伯利亚鲟对盐度的急性耐受力及行为反应, 待发表。

位,盐度到达25后继续养殖30天;(2)阶段增盐法(IT),每5天为1个阶段,每阶段盐度增加5,盐度到达25后继续养殖30d;(3)盐度突变法(IS),直接放入盐度为10的水中养殖10d,转入盐度20养殖10d,转入盐度25养殖30d。每一实验组样本数量30尾,各设3组平行。

每天投饵4次,按施氏鲟体质量的2%进行饲料投喂,并根据摄食情况进行具体调整,投喂后在0.5h内吃完为投喂最适量。详细记录投饵量,桶底剩余饵料及时收集,晾干后称重。每隔10天测量1次生长数据。驯化期间每2天换水1次(约为总体积的30%),盐度25后为循环水养殖,对照组换水等养殖条件同盐度驯化组。

本实验自2004年8月10日至9月30日,实验期间水温未加以控制,随着气温变化而变化,变化范围为24~29℃。监测各组水质情况,各实验组保持同一水平。

1.3 数据统计

对以下参数进行统计分析:

生长效率(Growth efficiency), $GE = [(W_2 - W_1)/F] \times 100\%$;

特定生长率(Specific growth rate, SGR), $SGR = [(\ln W_2 - \ln W_1)/(t_2 - t_1)] \times 100\%$;

摄食率(Feeding rate), $FR = 2F/[t^{-1}(W_2 + W_1)^{-1}] \times 100\%$;

食物转化率(Food conversion ratio, FCR), FCR

$= F/(W_2 - W_1)$;

以上各公式中的 W_1 、 W_2 为时间 t_1 、 t_2 时的平均体质量(g), t 为 t_2 与 t_1 之间的时间差, F 为饲料总摄入量, n 为实验个体数量。

实验数据通过STATISTICA(Version 6.0)统计软件(StatSoft, Inc.)进行处理分析,利用方差分析(One-Way ANOVA)来检验不同驯化模式对生长、摄食及食物转化率影响的显著性, $P < 0.05$ 为显著水平。

2 结果

2.1 施氏鲟对盐度变化的反应

在3种不同的驯化模式下驯化到盐度20时,IG、IT组表现正常,游泳、摄食未受任何影响;IS组转入20盐度2h左右时表现为鳃盖煽动频率和游泳速度均加快,摄食量减少,黏液分泌增加,但48h后恢复正常。驯化到盐度20后,施氏鲟的粪便由黑色逐渐变为白色,盐度为25时养殖15天后恢复正常。

2.2 存活及生长

实验期间,对照组(CT)及IT组均未发生死亡,而IG组死亡较为严重,成活率仅为85%,IS组的成活率为93.33%(表1),驯化方法对于施氏鲟的海水驯化成活率具有较大影响。IS、IG组施氏鲟死亡集中在盐度10到25的驯化阶段,而进入盐度为25的水中养殖30天并未发现死亡,并且实验组中死亡个体规格均较小。

表1 不同驯化模式下施氏鲟的存活及生长

Tab. 1 Survival and growth of juvenile *Acipenser schrenckii* under different acclimation method

项目 Item	实验组 Experimental treatment			
	CT	IG	IT	IS
初始体质量/g Initial BW	11.80 ± 2.82 ^a	12.45 ± 1.95 ^a	11.38 ± 3.54 ^a	12.00 ± 2.55 ^a
初始体长/cm Initial BL	11.05 ± 0.90 ^a	10.88 ± 0.57 ^a	11.05 ± 1.09 ^a	11.31 ± 0.97 ^a
最终体质量/g Final BW	48.11 ± 14.82 ^a	37.12 ± 9.43 ^b	29.45 ± 13.41 ^b	34.54 ± 14.05 ^b
最终体长/cm Final BL	18.38 ± 1.55 ^a	16.19 ± 1.66 ^{ab}	15.24 ± 2.18 ^b	16.2 ± 1.82 ^{ab}
生长效率/% GE	81.54 ± 27.97 ^a	68.32 ± 28.49 ^{ab}	58.53 ± 26.81 ^b	67.31 ± 25.65 ^{ab}
特定生长率/% SGR	3.06 ± 0.28 ^a	2.44 ± 0.41 ^{ab}	2.05 ± 0.38 ^b	2.51 ± 0.46 ^{ab}
成活率/% Survival rate	100 ± 0 ^a	85.33 ± 3.51 ^b	100 ± 0 ^a	93.33 ± 1.53 ^{ab}

注:1)CT-对照组,IG-盐度逐步递增组,IT-盐度梯度递增组,IS-盐度突变组;2)同一行参数上标字母相异则有显著差异($P < 0.05$)。

Note:1)CT-Control treatment;IG-Salinity increased gradually;IT-Salinity increased termly;IS-Salinity increased suddenly.2)Figures with different superscripts within each row are significantly different ($P < 0.05$).

在实验开始10天后(养殖水盐度为10左右,渗透压约为300 mmol/kg),对各组进行称重,发现各实验组(IG、IT、IS)的平均SGR为2.88,而CT组仅为2.0左右,各实验组在盐度10下的生长状况明显

优于CT组。经测量施氏鲟血清渗透压为(262.73 ± 6.22)mmol/kg($n = 5$),略低于盐度10的渗透压。由图1可见,IG和IS组SGR在第10天时(盐度10)达到最大值,在随后从盐度10驯化到25的过程

(第10到30天)中逐渐下降。驯化结束,养殖在盐度25下的SGR呈逐渐上升趋势。而IT组SGR自盐度10后一直处于下降趋势。从表1可以看出,CT组的最终体质量、SGR、GE等均高于各实验组,盐度对于施氏鲟生长具有重要影响。整个实验结束

时,IS组和IG组SGR与CT组无显著性差异($P > 0.05$),IT组显著($P < 0.05$)低于CT组。由此可见,尽管盐度对于施氏鲟的生长具有一定的影响,但是通过IG及IS方法驯化,施氏鲟在25盐度下仍然保持一定的生长速度。

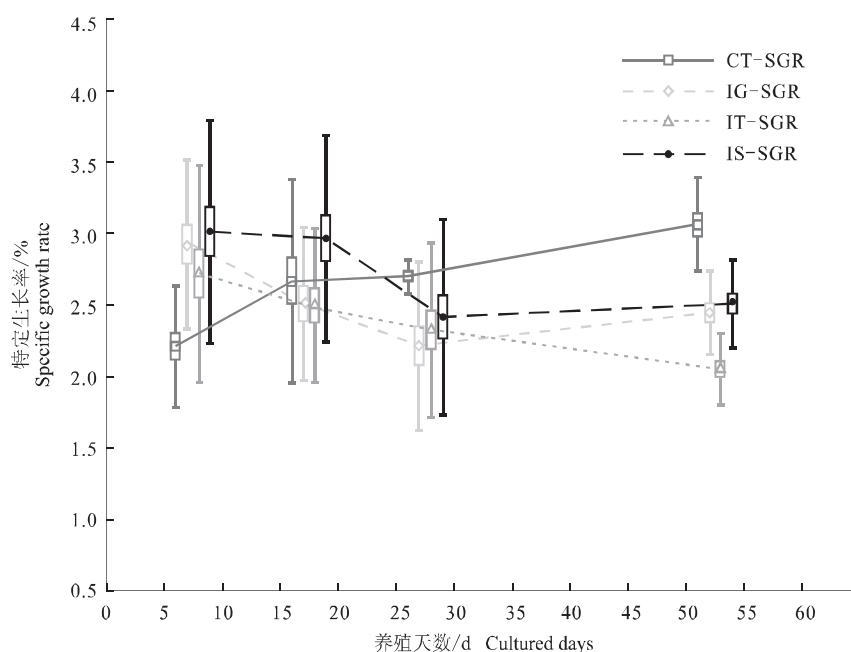


图1 施氏鲟盐度驯化过程中SGR变动情况($n=30$)

Fig. 1 SGR of juvenile *Acipenser schrenckii* under different acclimated intervals($n=30$)

2.3 摄食率及食物转化率

IG、IS、IT组与CT组相比,FR有所下降,但无显著差异($P > 0.05$)。IS组在盐度转换的前2天内表现为食欲下降,但后来恢复正常,0.5 h内施氏鲟

可以将所投饵料吃完。各驯化组FCR均低于CT组,统计分析后发现,对照组FCR与IG、IS组没有显著差异,与IT组差异显著($P < 0.05$)。

表2 不同驯化模式下摄食率及食物转化率

Tab. 2 Feeding rate and food conversion ratio under different acclimation methods during acclimation duration

$n=30; \bar{X} \pm SD$

项目 Item	实验组 Experimental treatment			
	CT	IG	IT	IS
摄食率/% FR	3.14 ± 0.75^a	3.02 ± 0.52^a	2.98 ± 0.26^a	3.10 ± 0.87^a
食物转化率/% FCR	1.16 ± 0.31^a	1.56 ± 0.72^a	2.12 ± 0.87^b	1.51 ± 0.53^a

注:1)CT:对照组,IG:盐度逐步递增组,IT:盐度梯度递增组,IS:盐度突变组;2)同一行参数上标字母相异则有显著差异($P < 0.05$)。

Note:1)CT: control treatment; IG: Salinity increased gradually; IT: Salinity increased ternly; IS: Salinity increased suddenly. 2) Figures with different superscripts within each row are significantly different ($P < 0.05$).

3 讨论

3.1 施氏鲟对盐胁迫效应的行为反应

鱼体具有泌乳素细胞,属于渗透敏感性细

胞^[4]。并且在鳃上有化学受体,可以感知水中的盐度变化。从淡水到海水,为了平衡水分的流失,鱼体会增加水的摄入量,饮水频率会明显加快。同时,消化道中大量水分会对消化酶的功能产生一定影

响^[1]。实验过程中施氏鲟粪便由黑色变为白色可能是消化道中某些消化酶的功能受到了影响,使其代谢产生暂时的紊乱所致。由于IS组盐度变化较大,施氏鲟表现的行为也较为突出,表现游泳速度加快,经过在盐度25的水中养殖适应后,恢复正常。而Rodríguez等^[6]在西伯利亚鲟(*Acipenser baerii*)的研究中发现,在盐度14下其表现为摄食减少,游泳速度减慢,个别鱼出现腹鳍基部充血,胸鳍腐烂等现象,在高于盐度14养殖环境下不能正常生长。与西伯利亚鲟行为表现相比,施氏鲟对盐度的耐受力要大于西伯利亚鲟。

3.2 盐度对施氏鲟存活、生长和摄食的影响

本实验中,施氏鲟驯化到盐度25时仍然保持较高的成活率,与方彰胜等^[7]的研究结果基本一致。施氏鲟对盐度的耐受力与湖鲟(*Acipenser fulvescens*)^[8]大致相仿,但大于西伯利亚鲟^[6]。施氏鲟在盐度驯化时,总是较小个体出现死亡,表明在一定盐度范围内,规格大小与盐度驯化成活率呈正比关系,这与湖鲟^[8]、意大利鲟(*Acipenser naccarii*)^[9]、高首鲟(*Acipenser transmontanus* Richardson)^[10]、虹鳟(*Salmo gairdneri*)^[11]、史匹罗罗非鱼(*Oreochromis spilurus spilurus*)^[12]等的研究结果一致。小个体首先死亡主要与其自身发育成熟情况(Maturational event)有关^[9-10],同时较小个体相对表面积与体积的比例要大于较大个体,渗透调节时能量消耗加大,这也是小个体死亡的原因之一^[13]。然而,在大麻哈鱼(*Oncorhynchus keta* Walbaum)^[14]和奥利亚罗非鱼(*Oreochromis aurea*)^[15]的研究结果中,较小个体却比较大个体更能适应高盐度的海水。

完成盐度驯化后,施氏鲟在盐度为25时养殖未发现死亡,证明盐度对于施氏鲟存活没有长期效应(Long-term effect)^[12],即经过适当驯化适应某一盐度环境后,养殖时间对于施氏鲟在这一盐度下的存活没有影响。

盐度为25时驯化各组SGR均显著低于对照组,证明施氏鲟在海水环境下生长受到一定的抑制,主要是因为渗透调节所需能量消耗增加导致的^[1]。然而,与其他研究相比^[16],盐度25的环境下施氏鲟仍保持较良好的生长速度^[17]。在盐度为10时施氏鲟的SGR明显优于淡水及更高盐度时的SGR。这与西伯

利亚鲟^[6]、湾鲟(*Acipenser oxyrinchus desotoi* Vladykov)^[18]和暗纹东方鲀(*Fugu obscurus*)^[19]相似。盐度10时渗透压略高于施氏鲟血液渗透压,在其等渗点附近。一般鱼类在等渗点盐度时生长速度最快,因为在等渗点盐度时用于渗透调节的耗能最少,能量消耗减少可以显著的促进生长^[20]。

施氏鲟FR在盐度条件下比淡水对照组中有所下降,但未表现出显著差异,这与Yan等^[19]得到的结果基本一致。在银大麻哈鱼(*Oncorhynchus kisutch*)^[21]、斑纹草鲷(*Trinectes maculatus*)^[22]和虹鳟(*Salmo gairdneri*)^[23]等研究中也发现了这种盐度增加而摄食率下降的现象。然而,在斑鲮(*Cyprinodon macularius*)^[24]和鲮(*Mugil cephalus*)^[25]的研究中却发现,盐度增加而摄食率也呈上升趋势。Lambert等^[26]通过实验证明,在盐度驯化过程中生长速度与饲料的摄入量之间没有明显相关性,而与饲料转化率及饵料成分(蛋白、脂肪、水)比例有关。

在不同鱼类中,盐度与FCR之间的关系主要表现为3种情况:①正相关^[27],即随盐度增加FCR也增加;②负相关¹⁾,即随盐度增加FCR下降;③FCR与盐度变化无关^[28]。本实验中,3种驯化模式下FCR都低于CT组,施氏鲟FCR与盐度的关系呈负相关趋势,即随着盐度的增加,FCR下降。

3.3 3种不同盐度驯化模式的比较

鱼类适应环境的能力可受环境的影响而有所强化^[29],许多淡水鱼类经过逐步驯化可以提高对盐度的适应性,逐步适应在高盐水环境中生存^[30]。施氏鲟为淡水种类,在盐度驯化过程中受到盐度的胁迫效应,IG组每天增加盐度,施氏鲟与渗透压调节相关的器官长期处于应激状态^[31],增加了本身的能量消耗,影响了正常的生理功能,这可能是IG组死亡率高的主要原因。IS组盐度变化幅度在施氏鲟可调节范围,而且盐度变化间隔时间长,施氏鲟有时间进行对盐度胁迫的生理调节和适应,故保持较高的成活率和生长速度。IT组在阶段驯化过程中,虽然能够克服盐度的胁迫效应,但由于同一盐度下驯化间隔较短,还未能对其完全适应,鱼体本身也基本处于连续应激状态,表现为生长较慢。淡水鱼类需要一定的时间来适应盐度的变化^[11,32]。

从本实验的结果来看,3种驯化方式的成活率

1) Watanabe W O, Ellingson L J, Wicklund R I, et al. The effects of salinity on growth, food consumption and conversion in juvenile, monosex male Florida red Tilapia [A]. Second International Symposium on Tilapia in Aquaculture. 1988. 515 - 523.

均在85%以上。IT组和IS组成活率均高于IG组,但是IT组SGR、GE及FCR等指标明显低于IG组和IS组。IG组在SGR、GE及FCR这3个指标上与IS组基本一致,但成活率较低,仅为85%。所以,在盐度驯化过程中采用盐度突变模式和逐步增盐法均可实现施氏鲟的盐度驯化,但盐度突变模式保持较高的SGR和成活率,并且操作步骤简单,较有利于施氏鲟的盐度驯化养殖,在实际的生产中可以根据当地的实际情况选择合适的驯化方法。

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Effects of different saltwater acclimation on growth and feeding of Amur sturgeon *Acipenser schrenckii*

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Abstract: Amur sturgeon (*Acipenser schrenckii*), originally distributed in the Heilongjiang River, is an promising culture species in China because of its fast growth and fine adaptation under different culture conditions. Most sturgeons are anadromous, and have good osmoregulatory capability. It is of significance in theory and practice for enriching seawater net-cage culture species and increasing culture profit to screen and acclimate Amur sturgeon to culture in seawater or brackish water condition. But no substantial information is available on growth and feeding of Amur sturgeon in seawater condition. In the present study, Amur sturgeons were acclimated to seawater through 3 different methods, which are: I Increased Gradually (IG), increase salinity every day with 1 salinity unit increment until salinity 25, then culture 30 d in salinity 25; II Increased Termly (IT), increase salinity every phase (1 phase includes 5 d) with 5 salinity unit increment until salinity 25, then culture 30 d at salinity 25; III Increased Suddenly (IS), directly culture in salinity 10 for 10 d, and then transfer into salinity 20 for another 10 d, finally culture in salinity 25 for 30 d. The Specific Growth Rate (SGR), Growth Efficiency (GE), Feeding Rate (FR), and Food Conversion Ration (FCR) were statistically analyzed and compared to the control group. The results showed that the acclimation methods affected the survival rate. The survival rate was 100% in IT group, 93.33% in IS group, 85% in IG group, respectively. The results showed the dead ones were always small. It mainly attributed to its mature event. And another reason was that the small ones, with more ratio of relative surface to volume than big ones, increased its energy costs. Under certain salinity, sturgeon's size was positively related to its tolerance to salinity. Salinity clearly influenced Amur sturgeon's growth in this experiment. SGR and GE of groups IG and IS were lower than those of group CT, but not significantly different ($P > 0.05$). They were significantly different with group IT. At salinity 10, sturgeons in all acclimated groups grow more faster than in control group. Energetic costs were the lowest in isotonic salinity, and these energy savings were enough to increase growth. Compared with group CT, FR in groups IG, IT and IS declined, but was not significantly different ($P > 0.05$). Mean FCR values among groups IG, IS and CT were not significantly different, but significantly different ($P < 0.05$) with group IT. FR and FCR of sturgeons were also affected by salinity and different acclimation methods. In conclusion, salinity affects the growth and feeding of Amur sturgeon, but Amur sturgeon at salinity 25 still has more growth potential with appropriate acclimated methods. Among the three acclimated methods, the method of increasing salinity suddenly (IS) is a good way to acclimate Amur sturgeon to seawater. [Journal of Fishery Sciences of China, 2006, 13(6): 945-950]

Key words: *Acipenser schrenckii*; seawater-acclimation; SGR; GE; FCR

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