

低温胁迫对许氏平鲈补偿生长的影响

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摘要:以体质量(60 ± 10) g、体长(13 ± 2) cm的许氏平鲈(*Sebastes schlegelii*)为研究对象,在8.5℃水体中低温胁迫1周(T₁组)、2周(T₂组)、3周(T₃组)后在20℃水体中恢复3周,研究其补偿生长。结果表明,低温胁迫后,T₁、T₂、T₃组体质量、生长率均显著低于对照组(C₁组,20℃);随低温胁迫时间的延长,鱼体脂肪含量逐渐降低,水分含量则逐渐增加,蛋白含量、能值与对照组差异不显著。经低温胁迫1周后,鱼体脂酶、SOD、CAT活力比对照组略有下降,但随胁迫时间的延长,3种酶活力均呈上升趋势。经4周恢复生长后,T₁、T₂组鱼体各项生化组分及免疫酶活力均恢复至对照组水平,而T₃组的鱼体脂肪、水分含量及免疫酶活力与对照组仍有显著差异,T₁、T₂组实现了完全补偿生长,而T₃组只实现了部分补偿生长。从摄食率、食物转化效率的变化曲线可知,经低温胁迫后许氏平鲈的补偿生长效应主要是通过提高食物转化效率实现的。[中国水产科学,2006,13(4):566-572]

关键词:许氏平鲈;低温胁迫;补偿生长

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由于自然界中季节更替、环境剧变或食物分布不均等原因,动物经常受到节律性或突发性胁迫。作为生理生态学上的一种适应,在恢复正常条件后动物会表现出超过正常个体生长速度的现象,称为补偿生长^[1-4]。但动物对胁迫的承受能力有限,超出其承受范围,动物非但不能恢复体质量,甚至导致持续性生长阻滞^[5-6]。

鱼类在其生活史中经常会受到温度胁迫。有研究表明温度胁迫可引起鱼类的补偿生长^[1,7],但关于温度胁迫对鱼类补偿生长的影响尚未见报道。

许氏平鲈(*Sebastes schlegelii*)是黄渤海近岸底层的重要经济鱼种,其生存温度范围较广(5~28℃),生长适宜温度为18~24℃^[8]。本实验主要研究低温胁迫不同时间对许氏平鲈生长、生化组分、免疫酶活力的影响,并初步分析许氏平鲈经不同时间低温胁迫后补偿生长的特点,以期对水产养殖技术的改善提供参考。

1 材料与方法

1.1 材料来源及暂养

实验用许氏平鲈取自青岛市薛家岛的海上网

箱。运回实验室后,在循环水槽中暂养2周。暂养用水为经过砂滤的自然海水,水温(20 ± 1)℃,盐度33,连续充气。每日早晚过量投喂人工配合饲料,2 h后吸出残饵及粪便。暂养结束后,选取体长(13 ± 2) cm,体质量(60 ± 10) g的个体用于实验。

1.2 实验设计及样品采集

实验在室内15个可控循环水族箱(80 cm × 50 cm × 50 cm)中进行。设对照组C及低温处理组T₁、T₂、T₃,共4组。对照组和处理组分别设6个、3个重复,每个重复用1个水族箱,每箱10尾鱼。实验期间,对照组水温保持在20℃不变。各处理组最初水温为20℃,每天降1~2℃,在1周内调至8.5℃。在8.5℃的条件下,T₁、T₂、T₃组再分别养殖1周、2周、3周后,进入恢复阶段。此时,各处理组的水温在1周内每天升高1~2℃,缓慢恢复至20℃,并在20℃条件下养殖3周。低温胁迫结束及恢复期的每周,测定实验鱼的体质量。胁迫及恢复结束时,从对照组中的1个箱内取出10尾鱼,各处理组每箱取3尾鱼,3个重复,共取9尾鱼。用于生化组分、免疫酶活力的测定。

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实验期间,各处理组每天按鱼体质量的10%投喂人工配合饲料2次,2 h后收集残饵,残饵烘干后称重。事先通过实验测定饵料溶失率,具体方法为:取定量 t (g)饵料烘干至恒重 t_1 (g)。再取重量为 t (g)饵料,放入2 h后收集残饵,烘干至恒重 t_2 (g)。饵料溶失率(%) = $100 \times (t_1/t_2)$ 。残饵量由饵料溶失率及干湿重比校正而得,并求得每日的摄食量。

1.3 样品制备及测定

在实验鱼尾椎动(静)脉取血,每尾鱼取0.3 mL。在4℃下血液经10 000 r/min离心20 min,制成血清,放于-32℃冰箱保存备用。血清溶菌酶活力按照Parry等^[9]的方法测定,超氧化物歧化酶(SOD)的活力测定采用联苯三酚自氧化法,过氧化氢酶(CAT)活力测定按照Beers和Sizer^[10]的方法,稍加改动。将取血后的鱼体样品于70℃烘干至恒重,求得水分含量。然后将同组3尾鱼研磨成细粉状后混合,放于-32℃冰箱保存待测。蛋白测定用凯氏定氮法,能量用1281型氧弹式热量计测定,脂肪测定采用乙醚抽提法。每一组的样品重复测定3次,取其平均值作为测定结果。

1.4 数据计算与统计分析

实验鱼的特定生长率(Specific growth rate, SGR)、摄食率(Feeding rate, FR)和食物转化效率(Food conversion efficiency, FCE)分别按下式计算:

$$\text{SGR}(\% \cdot \text{d}^{-1}) = 100 \times (\ln w_2 - \ln w_1) / t$$

$$\text{FR}(\% \cdot \text{d}^{-1}) = 100 \times C / [t \times (w_2 + w_1) / 2]$$

$$\text{FCE}(\%) = 100 \times (w_2 - w_1) / C$$

其中, w_1 和 w_2 分别为 t_1 和 t_2 时实验鱼的湿重(g), C 为摄食量(干重;通过饵料溶失实验进行校正)(g), t 为实验时间(d)。

所有实验数据经单因素方差分析(ANOVA),若差异显著再做Duncan's多重比较,以检验组间差异。以 $P < 0.05$ 为差异显著,所有分析均使用SPSS(11.5)软件进行。

2 结果

2.1 实验期间各组的体质量变化

从表1可以看出,低温胁迫后,各处理组体质量比对照组显著降低($P < 0.05$)。经1周低温胁迫的T₁组实验鱼在6周的养殖过程中,体质量平均增加20.40 g,而相同时间内对照组体质量平均增加22.54 g,T₁组与对照组差异不显著($P > 0.05$)。经2周低温胁迫的T₂组实验鱼在7周的养殖过程中,体质量平均增加20.54 g,相对应的对照组增加了24.46 g,2个组间差异也不显著($P > 0.05$)。经3周低温胁迫的T₃组实验鱼在8周的养殖过程中,体质量增加量仅为17.42 g,显著低于对照组的增加量($P < 0.05$)。

表1 实验期间许氏平鲈的体质量变化

Tab.1 Changes of body weight in rockfish (*Sebastes schlegelii*) during the experiment period (Mean ± SD)

		(X̄ ± SD)			
组	Group	胁迫前体质量/g Initial weight	胁迫后体质量/g Body weight after stress	恢复后体质量/g Final body weight	体质量增加量/g Change of body weight
T ₁	C ₁	62.86 ± 1.56	71.22 ± 1.10	85.40 ± 2.31	22.54 ± 0.75
	T ₁	61.68 ± 2.03	58.63 ± 1.36 *	82.08 ± 1.65	20.40 ± 0.38
T ₂	C ₂	62.86 ± 1.56	75.30 ± 2.61	87.32 ± 1.72	24.46 ± 0.16
	T ₂	66.45 ± 1.64	64.59 ± 2.01 *	86.99 ± 1.11	20.54 ± 0.53
T ₃	C ₃	62.86 ± 1.56	78.79 ± 1.73	90.45 ± 1.46	27.59 ± 0.10
	T ₃	63.13 ± 1.21	60.32 ± 1.46 *	80.55 ± 1.52 *	17.42 ± 0.31 *

注: * 表示与对照组有显著性差异($P < 0.05$)。

Note: * Asterisks indicate significant differences between test groups and control groups ($P < 0.05$).

2.2 生化组分

低温胁迫结束时,鱼体各生化组分含量的变化如表2所示。鱼体脂肪含量随胁迫时间的延长而降低,T₁、T₂、T₃3个处理组的脂肪含量分别比对照组下降6.92%、11.9%、12.6%,但T₁组与对照组差

异不显著,T₂、T₃组与对照组差异显著。T₁组鱼体水分含量比对照组略有增加($P > 0.05$),T₂、T₃组水分含量比对照组则显著增加($P < 0.05$)。各处理组鱼体蛋白含量比对照组略有下降,但差异不显著。各处理组鱼体能值与对照组无显著性差异。

尽管 T_1 、 T_2 组经受低温胁迫的时间不同,但经过 4 周的恢复生长,2 组鱼体的各项生化组分含量均恢复至对照组水平,与对照组差异不显著。但 T_3 组经恢复生长后,鱼体脂肪含量仍显著低于对照组,水分含量显著高于对照组,蛋白含量、能值与对照组仍无显著性差异。

2.3 免疫酶活力

T_1 组经 1 周低温胁迫后,溶菌酶、SOD、CAT 活力均低于对照组,但与对照组差异不显著。经 4 周

恢复生长, T_1 组 3 种酶活力接近对照组水平 ($P > 0.05$)。经 2 周低温胁迫的 T_2 组在胁迫及恢复期结束时,3 种酶活力均高于对照组,但与对照组差异不显著。经 3 周低温胁迫后, T_3 组的溶菌酶、SOD、CAT 活力分别比对照组高出 134.20 %、7.08 %、40.0 %,与对照组差异显著。经恢复生长后, T_3 组的 3 种酶活力虽有所下降,但仍显著高于对照组,分别比对照组高出 39.67 %、3.92 %、30.0 % (表 2)。

表 2 实验期间岩氏平鲈免疫相关酶学指标及生化组分的变化
Tab.2 Factors of the immune system and body composition of rockfish (*Sebastes schlegelii*) during the experiment period (Mean $\pm$ SD)

处理组 Treatments	阶段 Periods	免疫相关酶学指标 Factors of the nonspecific immunity			生化组分 Body composition			
		溶菌酶/(U·mL ⁻¹) Lysozyme	SOD/ (U·mL ⁻¹)	CAT/ (U·g ⁻¹ ·h ⁻¹)	水分/% Moisture	蛋白质/%(DW) Protein	脂肪/%(DW) Fat	能值/(kJ·g ⁻¹) (DW) Energy
T_1	胁迫结束 C_1	39.88 $\pm$ 13.54	409.70 $\pm$ 95.54	0.12 $\pm$ 0.02	68.23 $\pm$ 0.21	51.23 $\pm$ 0.42	30.45 $\pm$ 0.37	24.91 $\pm$ 0.39
	After stress T_1	34.93 $\pm$ 8.38	308.42 $\pm$ 21.63	0.08 $\pm$ 0.01	69.57 $\pm$ 0.72	50.85 $\pm$ 0.38	28.32 $\pm$ 0.43	24.59 $\pm$ 0.37
	恢复结束 C_1	47.22 $\pm$ 13.75	364.64 $\pm$ 11.01	0.10 $\pm$ 0.01	68.64 $\pm$ 0.82	52.35 $\pm$ 0.59	30.74 $\pm$ 0.61	25.82 $\pm$ 0.41
	After recovery T_1	46.06 $\pm$ 7.80	341.52 $\pm$ 6.79	0.10 $\pm$ 0.02	70.13 $\pm$ 0.50	51.24 $\pm$ 1.15	29.28 $\pm$ 0.37	26.04 $\pm$ 0.77
T_2	胁迫结束 C_2	31.33 $\pm$ 7.46	327.32 $\pm$ 8.56	0.09 $\pm$ 0.01	68.78 $\pm$ 0.43	52.25 $\pm$ 0.36	30.10 $\pm$ 0.18	24.49 $\pm$ 0.23
	After stress T_2	43.67 $\pm$ 8.03	328.13 $\pm$ 5.79	0.11 $\pm$ 0.027	0.31 $\pm$ 0.28*	51.61 $\pm$ 0.85	26.25 $\pm$ 0.59*	24.62 $\pm$ 0.20
	恢复结束 C_2	39.41 $\pm$ 10.65	413.04 $\pm$ 23.85	0.08 $\pm$ 0.01	68.90 $\pm$ 0.28	52.07 $\pm$ 0.67	29.08 $\pm$ 0.36	25.16 $\pm$ 0.31
	After recovery T_2	44.97 $\pm$ 7.18	432.32 $\pm$ 8.93	0.09 $\pm$ 0.02	70.16 $\pm$ 0.37	50.03 $\pm$ 0.71	28.83 $\pm$ 0.27	25.48 $\pm$ 0.20
T_3	胁迫结束 C_3	42.13 $\pm$ 6.83	346.34 $\pm$ 5.57	0.10 $\pm$ 0.02	68.06 $\pm$ 0.77	51.03 $\pm$ 0.71	30.23 $\pm$ 0.62	24.01 $\pm$ 0.45
	After stress T_3	98.67 $\pm$ 11.83*	370.89 $\pm$ 15.12*	0.14 $\pm$ 0.02*	70.39 $\pm$ 0.28*	49.57 $\pm$ 0.64	25.43 $\pm$ 0.20*	24.35 $\pm$ 0.79
	恢复结束 C_3	51.72 $\pm$ 3.23	413.04 $\pm$ 23.85	0.10 $\pm$ 0.02	68.18 $\pm$ 0.22	51.84 $\pm$ 0.15	29.74 $\pm$ 0.41	25.16 $\pm$ 0.56
	After recovery T_3	71.24 $\pm$ 9.55*	429.24 $\pm$ 10.05*	0.13 $\pm$ 0.03*	65.02 $\pm$ 0.23*	51.41 $\pm$ 0.54	26.89 $\pm$ 0.15*	25.25 $\pm$ 0.10

注: * 表示处理组与对照组有显著性差异 ($P < 0.05$)。

Note: * Asterisks indicate significant differences between test groups and control groups ($P < 0.05$).

2.4 特定生长率(SGR)

随低温胁迫时间的延长,各处理组实验鱼特定生长率(SGR)逐渐下降, T_1 、 T_2 、 T_3 组 SGR 分别比对照组下降 61.67 %、66.67 %、75.34 %。在恢复阶段, T_1 组 SGR 的增加出现延迟,在恢复 2 周后升至最高值,而后逐渐下降。经 4 周恢复后, T_1 组 SGR 接近对照组水平 ($P > 0.05$)。在整个恢复过程中, T_2 、 T_3 组 SGR 在对照组水平附近呈波动变化。至实验结束时, T_2 组 SGR 恢复至对照组水平 ($P > 0.05$), T_3 组 SGR 比胁迫结束时略有上升,但仍显著低于对照组 ($P < 0.05$) (表 3)。

2.5 摄食率(FR)

胁迫结束时,3 个处理组摄食率(FR)均显著低

于对照组。在恢复阶段,第 1 周时 T_1 组 FR 稍许下降后,显著上升,在第 3 周时升至对照组水平 ($P > 0.05$); T_2 、 T_3 组 FR 则始终低于对照组。至实验结束时, T_1 组 FR 与对照组无显著性差异 ($P > 0.05$),而 T_2 、 T_3 组均显著低于对照组 ($P < 0.05$) (表 3)。

2.6 食物转化效率(FCE)

胁迫结束时,3 个处理组的食物转化效率(FCE)与对照组无显著性差异。在恢复阶段, T_1 组 FCE 均高于对照组, T_2 、 T_3 组 FCE 在对照组水平附近呈波动变化。至实验结束时, T_1 、 T_2 组 FCE 显著高于对照组,而 T_3 组则略低于对照组 ($P > 0.05$) (表 3)。

表3 许氏平鲈在水温 8.5℃ 胁迫后各恢复阶段特定生长率、摄食率、食物转化效率的变化
Tab.3 Changes in specific growth rate, feeding rate, and food conversion efficiency of rockfish (*Sebastes schlegelii*)
subjected to 8.5℃ stress during the recovery period (Mean ± SD) ($\bar{X} \pm SD$)

指标 Indexes	处理组 Treatments	阶段 Periods				
		胁迫结束 After stress	恢复 1 周 Recovery for one week	恢复 2 周 Recovery for two weeks	恢复 3 周 Recovery for three weeks	恢复 4 周 Recovery for four weeks
特定生长率 SGR/(%·d ⁻¹)	C ₁	0.59±0.01	0.51±0.02	0.71±0.04	0.48±0.01	0.49±0.06
	T ₁	0.23±0.03 *	0.13±0.05 *	0.90±0.01 *	0.81±0.03 *	0.58±0.02
	C ₂	0.51±0.02	0.71±0.04	0.48±0.01	0.49±0.06	0.50±0.02
	T ₂	0.17±0.03 *	0.07±0.05 *	0.84±0.02 *	0.29±0.03 *	0.62±0.01
	C ₃	0.71±0.04	0.48±0.01	0.49±0.06	0.50±0.02	0.56±0.01
	T ₃	0.18±0.05 *	0.85±0.03 *	0.39±0.01	0.54±0.01	0.25±0.02 *
摄食率 FR/(%·d ⁻¹)	C ₁	9.46±0.78	8.77±0.29	14.64±0.10	11.28±0.47	14.55±4.89
	T ₁	2.32±0.32 *	1.79±0.35 *	7.74±0.49 *	10.91±0.56	9.48±0.78
	C ₂	8.77±0.29	14.64±0.10	11.28±0.47	14.55±4.89	10.15±0.85
	T ₂	2.05±0.83 *	3.53±0.57 *	7.47±0.64 *	8.76±0.18 *	4.52±0.72 *
	C ₃	14.64±0.10	11.28±0.47	14.55±4.89	10.15±0.85	12.26±0.34
	T ₃	2.57±0.61 *	8.03±0.68 *	12.11±0.96	4.49±0.15 *	4.53±0.38 *
食物转化效率 FCE/%	C ₁	16.65±3.18	11.75±1.64	13.04±1.22	9.50±1.47	9.76±1.49
	T ₁	22.48±3.51	21.25±3.45 *	23.14±1.42 *	20.03±1.34 *	16.73±2.02 *
	C ₂	11.75±1.64	13.04±1.22	9.50±1.47	9.76±1.49	8.26±1.64
	T ₂	17.09±2.87	4.33±1.52 *	33.69±1.58 *	4.27±1.65	35.09±1.30 *
	C ₃	13.04±1.22	9.50±1.47	9.76±1.49	8.26±1.64	9.14±2.89
	T ₃	17.68±2.57	24.32±2.13 *	7.69±0.88	39.37±1.58 *	3.13±0.67

注: * 表示处理组与对照组有显著性差异 ($P < 0.05$)。

Note: * Asterisks indicate significant differences between test groups and control groups ($P < 0.05$).

3 讨论

3.1 许氏平鲈在低温胁迫及恢复生长后生化组分含量的变化

目前,对于鱼类补偿生长主要是研究继饥饿或营养不足后的补偿生长现象,而对于鱼类继温度胁迫后补偿生长的研究还较少。本研究发现许氏平鲈继低温胁迫后,体内生化组分含量的变化与其他一些鱼类继饥饿后的生化组分含量的变化趋势相似^[11-13]。许氏平鲈体内脂肪含量随低温胁迫时间的延长而降低, T₂、T₃组分别比对照组显著降低 11.9%、12.6%, T₁组比对照组也略有降低 ($P > 0.05$)。而胁迫结束时,实验鱼体内蛋白质含量、能值与对照组差异不显著。由此表明,在长时间低温胁迫过程中,许氏平鲈主要以脂肪作为能量来源。伴随着体内脂肪的消耗,水分的相对含量逐渐增加。Sullivan^[14]也指出鱼体脂肪在淡水鱼类忍受胁迫(低温、饥饿等)过程中发挥重要作用。在大菱鲆

(*Scophthalmus maximus*)^[15]、鲈鱼(*Dicentrarchus labrax*)^[16]、鲤(*Cyprinus carpio*)^[17]的研究中也发现,一定范围内的温度变化对实验鱼体内的蛋白质、能值无显著影响。而 El-Sayed 等^[18]发现,随着温度的降低(33℃→5℃),尼罗罗非鱼(*Oreochromis niloticus* L.)体内脂肪、蛋白含量急剧下降。这些实验结果的差异可能与鱼种、实验鱼的营养储备及胁迫强度等因素有关^[12]。

本研究中,经 4 周恢复生长, T₁、T₂组鱼体各项生化组分含量均恢复至对照组水平 ($P > 0.05$),但 T₃组的脂肪、水分含量与对照组仍有显著差异。表明,经 1~2 周短时间的低温胁迫后许氏平鲈可实现其补偿生长,但胁迫时间超过 2 周,在较短的恢复周期内将不能实现其在生化组分方面的补偿生长。

3.2 许氏平鲈在低温胁迫及恢复生长后免疫酶活力的变化

溶菌酶主要针对革兰氏阳性菌发挥作用,其活力越强,溶菌能力也就越高,是鱼类非特异性免疫系

统的重要组成部分。超氧化物歧化酶(SOD)、过氧化氢酶(CAT)可保护机体细胞免受活性氧自由基的伤害,是抗氧化防御系统的关键酶^[19]。鱼体内溶菌酶及抗氧化酶(SOD、CAT)活力能随着环境因素如温度、盐度、溶解氧等的变化而变化^[20-22]。本实验中经1周低温胁迫后,许氏平鲈体内溶菌酶、SOD、CAT活力比对照组略有下降($P>0.05$),但差异不显著。推测是短时间处于低温条件下,导致实验鱼整体的代谢水平下降,各种酶活力也有所降低。但随着低温胁迫时间的延长,3种酶活力均呈上升趋势,且T₃组酶的活力已显著高于对照组。表明鱼体在经历了较长时间的低温胁迫后会产生一种应激和保护反应,以此增强机体免疫力。该结果支持了Fevolden等^[23]认为溶菌酶活性可作为鱼类应激的信号,其水平升高所持续的时间依胁迫的方法和强度而定的论点。但陈昌樞等^[24]在对草鱼(*Ctenopharyngodon idellus*)的研究中发现,在10℃水温条件下经为期5周养殖实验,草鱼血清溶菌酶活性呈下降趋势,并认为是由于营养缺乏导致其活性的相对下降。本研究中T₃组的SOD、CAT活力在胁迫后也显著升高,推测长时间的低温胁迫导致鱼体内产生大量活性氧自由基,而SOD、CAT活力升高可清除这些活性氧自由基,从而保护体细胞免受其伤害。

经4周恢复生长后,T₁组各种酶活力恢复至对照组水平,T₂组略高于对照组,T₁、T₂组与对照组间均无显著性差异。表明虽然1~2周的低温胁迫会影响鱼体免疫力,但经过4周恢复生长,鱼体的抗病免疫力在一定程度上可以恢复到正常水平。但T₃组经恢复生长后鱼体内各种酶活力虽有所下降,但仍显著高于对照组。表明T₃组实验鱼经4周恢复生长,鱼体应激状态虽然得到一定缓解,但还未完全恢复至正常状态。

3.3 许氏平鲈的补偿生长及其机制

谢小军等^[25]从补偿量角度将鱼类的补偿生长分为4类:超补偿生长、完全补偿生长、部分补偿生长和不能补偿生长。本实验中,T₁、T₂处理组在恢复生长结束时,体质量、生长率与对照组差异均不显著,表明许氏平鲈经1~2周低温胁迫后,具有完全补偿生长的能力。T₃组进入恢复阶段的初期,生长速度较对照组有所加快,但持续时间较短,而后在对照组上下呈波动变化。至实验结束时,T₃组体质量、生长率、摄食率均显著低于对照组。即3周的低

温胁迫超出了许氏平鲈的调节范围,在恢复至正常条件后,只能实现部分补偿生长。T₃组由于低温胁迫时间较长,至实验结束时,鱼体内各免疫酶活力与对照组也有显著性差异,表明鱼体仍处于应激状态。所以,在养殖生产中,应尽量避免使鱼类长时间处在低温条件下。Nicieza和Metcalf^[1]发现经低温处理的大西洋鲑(*Salmo salar*)也能表现出部分补偿生长现象。在 (5.6 ± 1.7) ℃水温条件下养殖37 d的大西洋鲑,在恢复至室温后的8~50 d和80~215 d 2个阶段,鱼体生长速度显著高于对照组,但至215 d实验结束时鱼体质量未能赶上对照组。而Mortensen和Damsgard^[27]发现,在2℃低温下饲养50 d的大西洋鲑和北极红点鲑(*Salvelinus alpinus* L.),转入9℃水体70 d后,仍能表现出超补偿生长现象。可见补偿生长能力的高低和有无取决于鱼的种类和大小、胁迫的程度和持续时间以及恢复生长时间的长短。更确切地说取决于SGR升高的幅度和持续的时间^[26]。

动物主要是通过提高食物转化率^[27-28],或增加摄食量^[29-30],或通过两种因素协同作用实现补偿生长^[31]。Nicieza和Metcalf^[1]认为大西洋鲑经低温胁迫后可能是通过直接提高食物转化率来实现其部分补偿生长的。本实验中,各低温处理组许氏平鲈在恢复生长过程中摄食率较对照组均无明显升高,而T₁组食物转化效率均高于对照组,T₂、T₃组食物转化效率在对照组水平上下呈波动变化并与其特定生长率变化规律相似,由此说明,许氏平鲈在低温胁迫后的恢复生长中出现的补偿效应主要是通过提高食物转化效率实现的。

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Compensatory growth of rockfish (*Sebastes schlegeli*) following low temperature stress

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Abstract: Compensatory growth refers to the rapid growth spurt that follows a period of being exposed to undernutrition or other unfavorable environmental conditions, which result in the growth depression of animals. Compensatory growth has been reported in lots of animals, including fish. Most studies on compensatory growth in fish have dealt with just one of the possible causes of growth depression, namely, food shortage. Nevertheless, few studies have examined compensatory growth of fish after temperature stress. Therefore, in the present study compensatory growth of rockfish after different periods of temperature stress was studied. The experiment lasted for 8 weeks and was divided into two periods, temperature stress period and recovery period. The control fish were kept at 20 °C throughout the experiment. Fish in other three groups were subjected to three periods of low temperature (8.5 °C) stress as following: one week (group T₁), two weeks (group T₂) and three weeks (group T₃). When the stress ended, the temperature of the three groups were increased gradually to 20 °C in a week and then were kept at 20 °C during the following 3 weeks. When the fish were held at 8.5 °C for more than 1 week, the lipid contents of the fish decreased, and water contents increased, while the protein and energy contents were not significantly different from the controls. After recovery at 20 °C for 3 weeks, all parameters of biochemical compositions of group T₁ and T₂ restored to those of the controls, but the lipid and water contents of group T₃ were still significantly different from the controls. It indicated that after low temperature stress for one or two weeks, rockfish could achieve compensation in body composition after 4-week recovery, while after stress for more than two weeks, it could not compensate in this short period. At the end of low temperature-stress periods, the activities of lysozyme, SOD, CAT of group T₁ were slightly lower than those of the controls. However, the three indexes of group T₂ and T₃ increased. When the recovery periods ended, the activities of lysozyme, SOD, CAT of group T₁ and T₂ had no significant differences from the controls, while group T₃ were still significantly higher than the controls. It showed that the temperature stress could influence the immunity of rockfish. But after 4-week recovery, the immunity of fish subjected low level of temperature-stress (for one or two weeks) could return to that of the control fish. The body weight and specific growth rate (SGR) of stressed fish were significantly lower than the controls after stress. At the end of the recovery period, group T₁ and T₂ completely compensated and group T₃ partly compensated the growth depression. By analyzing the data of feeding rate and food conversion efficiency during the recovery period, it was concluded that the compensatory growth of rockfish after low temperature-stress mainly depended on improving food conversion efficiency (FCE). [Journal of Fishery Sciences of China, 2006, 13(4): 566-572]

Key words: *Sebastes schlegeli*; low temperature stress; compensatory growth

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