Chinese Journal of Applied Ecology, Jun. 2016, 27(6): 1959-1967 DOI: 10.13287/j.1001-9332.201606.026

温度与光周期对白头鹎体质量、能量收支和消化道形态的影响

王润梅[1] 吴玉南[1] 梁洪基[1] 林 琳[1] 郑蔚虹[1,2] 柳劲松[1,2*]
([1]温州大学生命与环境科学学院, 浙江温州 325035; [2]温州大学应用生态研究所, 浙江温州 325035)

摘 要 温度与光周期是环境季节性变化的最直接表现因子及时间变化指示标志,对动物的形态、生理及行为产生重要的影响.本文以白头鹎为研究对象,探讨了不同温度与光周期对其体质量、能量收支和消化道形态的影响,分析了能量收支与消化道形态特征的关系.将 28 只白头鹎(12 雄 16 雌)分为 4 组:暖温长光组(30 ℃,16 L∶8 D;3 雄 4 雌)、暖温短光组(30 ℃,8 L∶16 D;3 雄 4 雌)、低温长光组(10 ℃,16 L∶8 D;3 雄 4 雌)和低温短光组(10 ℃,8 L∶16 D;3 雄 4 雌).结果表明: 低温与短光照可促进白头鹎的体质量、摄入能及同化能明显增加,同时温度与光周期的交互作用对白头鹎的摄入能及同化能影响显著.低温条件下,胃、小肠、直肠及总消化道的湿质量及干质量明显增加.残差分析表明,小肠与总消化道的长度及干质量与摄入能和同化能显著相关.表明低温与短光照下白头鹎通过增加体质量、能量摄入和改变消化道形态来应对严酷的环境条件.

关键词 白头鹎; 温度; 光周期; 体质量; 能量收支; 消化道形态

Effects of temperature and photoperiod on body mass, energy budget and digestive tract morphology in *Pycnonotus sinensis*. WANG Run-mei[1], WU Yu-nan[1], LIANG Hong-ji[1], LIN Lin[1], ZHENG Wei-hong[1,2], LIU Jin-song[1,2*] ([1] *School of Life and Environmental Sciences, Wenzhou University, Wenzhou* 325035, *Zhejiang, China*; [2] *Institute of Applied Ecology, Wenzhou University, Wenzhou* 325035, *Zhejiang, China*).

Abstract: Temperature and photoperiod are proximate environmental factors that have an important influence on the morphological, physiological and behavioral adjustments animals performance during seasonal acclimatization. In this study, the effects of temperature and photoperiod on phenotypic flexibility in body mass, energy budget and digestive tract morphology in the Chinese bulbul (*Pycnonotus sinensis*) were examined, and the relationship between energy budget and digestive tract morphology was analyzed. Twelve male and sixteen female Chinese bulbuls were randomly assigned into 4 experimental groups so that each group was comprised of three males and four females. The groups were: 1) a warm and long photoperiod (30 ℃, 16 light: 8 dark) group, 2) a warm and short photoperiod (30 ℃, 8 light: 16 dark) group, 3) a cold and long photoperiod (10 ℃, 16 light:8 dark) group, and 4) a cold and short photoperiod (10 ℃, 8 light: 16 dark) group. Each group was acclimated to its respective temperature and photoperiod for 4 weeks. Birds in the cold temperature and short photoperiod group underwent a significant increase in body mass, gross energy intake (GEI) and digestible energy intake (DEI) compared to the other three groups, and there was a significant interaction between temperature and photoperiod on gross energy intake and digestible energy intake. The mass of the stomach, small intestine, rectum, and total digestive tract, all increased significantly in cold temperature treatment groups compared to those acclimated to a relatively warm temperature. There was a significant, positive correlation between GEI and DEI residuals and those of the length and dry mass of the small intestine and total digestive tract. These results suggested that the Chinese bulbul met the increased energy demands of winter (colder tempe-

本文由国家自然科学基金项目(31070366,31470472)、国家大学生“创新创业计划”项目和浙江省“新苗计划”项目资助 This work was supported by grants from the National Natural Science Foundation of China (31070366, 31470472), the National Undergraduate Innovation and Entrepreneurship Training Program and the Zhejiang Province “Xinmiao” Project.
2015-10-15 Received, 2016-03-21 Accepted.
* 通讯作者 Corresponding author. E-mail: ljs@wzu.edu.cn

ratures and reduced foraging time due to shorter day-length) by increasing its body mass, digestible energy intake and digestive tract size.

Key words: Chinese bulbul (*Pycnonotus sinensis*); temperature; photoperiod; body mass; energy budget; digestive tract morphology.

鸟类是生态系统的重要组成部分,在维持生物圈稳态方面有着重要作用.与很多动物一样,在环境因子或自身生理条件发生变化的情况下,鸟类也会表现出形态及生理的表型可塑性,以适应环境变化和维持生存[1-2].小型鸟类因体型较小,相对体表面积大,使得产热代谢及能量调节成为其适应外界环境条件的重要生存策略[3].表型可塑性(phenotypic plasticity)是有机体在不同环境中表现不同特征的能力[4].这种特征的改变具有可逆性和可重复性,反映了动物对环境的适应能力.表型的改变包括行为、生理、形态及生活史对策等[5].对表型可塑性的研究已经成为进化生态学的主题之一,阐明推动代谢率进化的选择压力有助于了解鸟类在形态学、生理学、行为学和生活史对策上的进化[4-7].

保持最适能量平衡是动物的主要生存对策之一,对物种分布、丰富度、适合度等有重要影响[8].许多鸟类面临气候变化和食物供给等季节性问题,如冬季白天的缩短影响取食效率,为此鸟类通过形态、生理和行为等方面的调整来适应不同季节的能量需求,包括改变体质量、增加能量摄入和改变消化道形态等来应对不利的环境条件[9-13].作为食物消化吸收的场所,动物消化道形态结构与食性、食物质量及相关能量营养吸收有着密切联系[5,14].同时,消化器官储存、消化和吸收营养物质的能力是限制能量收支的关键,也是动物成功适应生存环境的关键[15-16].目前已见国内外不少有关环境条件变化对小型鸟类能量代谢方面的研究报道[17-19],并发现温度是影响小型鸟类能量代谢的主要环境因子之一[20-22],低温会导致白头鹎(*Pycnonotus sinensis*)[23]和家麻雀(*Passer domesticus*)[24]等鸟类能量摄入显著增加.以往有关光周期对小型鸟类的生理影响研究主要关注于鸟类生长、发育、免疫系统及繁殖等方面[25-28],最新研究发现,光周期也是影响小型鸟类能量代谢的重要环境因素,其中短光照下鸟类表现出更高的能量代谢水平[20,29-30].

白头鹎(*Pycnonotus sinensis*)属雀形目鹎科,在浙江省温州地区为留鸟.白头鹎食性很杂,并随季节发生变化,春夏季以动物性食物为主,秋冬两季主要吃植物性食物[31].伴随全球气候变暖,白头鹎在过去 10 多年来不断向北方扩散,先后在北京、河北、青海和辽宁等地被列为新分布种[32].已发现白头鹎具有较高的体温、较低的基础代谢率(basal metabolic rate, BMR)和较宽的热中性区[33],其代谢产热存在明显的昼夜节律和季节性变化[34-35].内部器官(如肝脏、心脏、肾脏和消化道)及肌肉质量都与 BMR 的大小呈正相关,冬季肝脏和肌肉的线粒体呼吸、细胞色素氧化酶活力及甲状腺激素明显高于夏季[36-37].同时温度或光周期对白头鹎的体质量、器官质量、BMR 及能量收支有着一定影响,并且短光照和较长光照更能引起白头鹎体质量、器官质量及能量代谢的明显变化[20,23,38-40].本研究拟通过测定不同环境温度(暖温和低温)和光周期(长光和短光)条件下白头鹎的体质量、能量收支及消化道形态等指标,探明白头鹎的消化生理特征,揭示白头鹎能量收支和消化道形态在不同环境温度和光照条件下的变化及其适应策略.

1 研究区域与研究方法

1.1 研究地点

温州地区(27°29′ N,120°51′ E)气候温暖,年平均降雨量 1700 mm,每季均有降雨,其中以春、冬两季降雨量较高.年平均气温 18 ℃,平均最高气温(7 月)39 ℃,平均最低气温(1 月)3 ℃[33-34].

1.2 供试动物

28 只(12 ♂、16 ♀)白头鹎于 2011 年 3 月捕自浙江省温州地区,标记并单笼(60 cm×60 cm×30 cm)饲养于温州大学动物实验房,在自然光照、室温的环境条件下自由饮水、取食(食物为江苏谢通生物工程有限公司生产的饲料:粗蛋白 20%,粗脂肪 6%,粗纤维 4%,钙 1%,赖氨酸0.5%,蛋氨酸+胱氨酸 0.5%).适应一周后用于试验.供试动物及试验条款已经得到温州市动植物保护协会的批准.因雌雄白头鹎的体质量、能量收支和消化道等各项指标均未出现显著差异($P>0.05$),故将雌雄白头鹎合并一组.

1.3 温度和光周期试验

适应一周后,采用双因子(温度×光周期)试验设计,随机将白头鹎分为 4 组:暖温长光组(30 ℃,16 h 长光∶8 h 短光,16 L∶8 D,3 ♂4 ♀)、暖温短光

组(30 ℃,8 h 长光∶16 h 短光,8 L∶16 D,3♂4♀)、低温长光组(10 ℃,16 h 长光∶8 h 短光,16 L∶8 D,3♂4♀)组和低温短光组(10 ℃,8 h 长光∶16 h 短光,8 L∶16 D,3♂4♀),分别于温州大学人工气候室中适应 28 d[41].

1.4　测定方法

1.4.1 体质量　采用电子天平(PL3001-S,精确度±0.1 g,瑞士梅特勒)测定适应前(第 0 天)及适应后(第 28 天)白头鹎的体质量.

1.4.2 体温　以泄殖腔温度代表体温,用数字式温度测量仪(TH-212,精确至 0.1 ℃,北京师范大学司南仪器厂)插入泄殖腔内约 1.5 cm 处测定约 30 s,待数值恒定后读数[6,23],测定适应前(第 0 天)及适应后(第 28 天)白头鹎的体温.

1.4.3 能量收支　测定适应前(第 0 天)及适应后(第 28 天)白头鹎的摄入能(GEI, kJ·d^{-1})和排泄能(FE, kJ·d^{-1}),并计算其同化能(DEI, kJ·d^{-1})及同化率(%).定时定量给动物喂食并称量动物体质量.称量及剩余食物、粪便的收集分别在第 0 天(试验前 3 天的平均值)和第 28 天(试验后 3 天的平均值)进行,每次收集时间均在 13:00—15:00.收集的食物和粪便在 65 ℃的烘箱中干燥至恒量后称量,并用氧弹热量计(C200,德国 IKA)测定热值.能量收支计算根据下列公式[13,42]:

GEI=摄入干物质量(g·d^{-1})×食物热值(kJ·g^{-1})

FE=粪便干质量(g·d^{-1})×粪便热值(kJ·g^{-1})

DEI=GEI−FE

同化率=DEI/GEI×100%

1.4.4 消化道质量及长度　能量收支测定结束后,于次日将动物颈部错位处死,称量后进行解剖.取出消化道,分离出胃、小肠和直肠.剔除肠系膜及脂肪组织,各部平展为自然状态下最大长度(不拉伸),用游标卡尺(精度±1 mm)测定长度.用剪刀将各器官纵向剖开,在生理盐水中清洗以除去肠道内容物,滤纸吸干生理盐水,用电子天平(BS210-S,精确度±0.1 mg,瑞士梅特勒)称量各器官湿质量.将各器官置于 65 ℃烘箱烘干至恒量,称量各器官干质量.总消化道的各项指标均为胃、小肠和直肠的相加值[10,40].

1.5　数据处理

利用 SPSS 11.5 统计软件包进行相关统计分析,组间各项指标采用 Kolmogorov-Smirnov 检验,非正态分布数据转换为自然对数.组间体质量、体温与同化率差异采用双因素方差分析(two-way ANOVA);组间摄入能、排泄能、同化能、胃、小肠、直肠及总消化道差异采用双因素协方差分析(two-way ANCOVA)(体质量为协变量).消化器官对体质量作异速回归分析,消化道与摄入能和同化能的相关分析采用最小二乘线性残差分析.文中数据均以平均值±标准误(mean±SE)表示,$P<0.05$ 即认为差异显著.

2　结果与分析

2.1　温度和光周期对白头鹎体质量和体温的影响

2.1.1 体质量　从表 1 可以看出,试验前各组间白头鹎体质量没有显著差异(温度:$F_{1,24}=0.476$, $P>0.05$;光周期:$F_{1,24}=0.527$, $P>0.05$;交互作用:$F_{1,24}=0.193$, $P>0.05$).当适应 28 d 后,温度和光周期对白头鹎体质量有明显的影响(温度:$F_{1,24}=8.027$, $P<0.05$;光周期:$F_{1,24}=9.204$, $P<0.05$),而温度和光周期的交互作用对白头鹎体质量无明显影响($F_{1,24}=0.091$, $P>0.05$).低温短光组白头鹎的体质量

表 1　温度和光周期对白头鹎体质量和能量收支的影响

Table 1　Effects of temperature and photoperiod acclimation on body mass and energy budget in *Pycnonotus sinensis* (mean±SE, $n=7$)

温度 Temperature	光周期 Photoperiod	体质量 Body mass (g)		体温 Body temperature (℃)		摄入能 GEI (kJ·d^{-1})		排泄能 FE (kJ·d^{-1})		同化能 DEI (kJ·d^{-1})		同化率 Digestibility (%)	
		初始 Initial	最终 Final	初始 Initial	最终 Final	初始 Initial	最终 Final	初始 Initial	最终 Final	初始 Initial	最终 Final	初始 Initial	最终 Final
暖温	L	26.5±	24.6±	42.6±	42.1±	158.86±	133.49±	82.65±	39.47±	76.21±	74.02±	48.44±	65.17±
Warm		1.6	1.6b	0.5	0.5	26.30	15.67c	19.55	8.17b	9.77	13.15c	4.87	5.71a
temperature	S	26.8±	26.3±	42.8±	42.3±	157.42±	112.14±	79.65±	33.25±	77.77±	78.89±	49.61±	70.61±
		2.5	2.3b	0.2	0.9	23.89	11.44c	15.48	6.74b	9.68	5.18c	3.01	3.34a
低温	L	26.7±	26.1±	42.5±	42.4±	167.10±	164.95±	88.39±	68.88±	78.71±	96.06±	47.42±	58.41±
Cold		1.5	1.4b	0.5	0.5	24.08	14.95b	17.66	11.93a	8.62	7.45b	3.95	3.97b
temperature	S	27.7±	29.6±	42.9±	42.9±	149.74±	205.71±	73.54±	82.14±	76.21±	123.57±	51.30±	60.25±
		2.6	3.3a	0.3	0.4	27.94	16.16a	18.29	11.85a	11.00	5.05a	3.43	2.83b
显著性		ns	T*,	ns	ns	ns	T*, P*,	ns	T*,	ns	T*, P*,	ns	T*,
Significance			P*				T×P*		T×P*		T×P*		P*

T: 温度 Temperature; P: 光周期 Photoperiod. L: 长光 Long day; S: 短光 Short day. 同列不同字母表示处理间差异显著($P<0.05$) Different letters in the same column meant significant difference among treatments at 0.05 level. *$P<0.05$; ns: $P>0.05$. 下同 The same below.

分别比暖温长光组、暖温短光组和低温长光组高出20%、13%和13%.

2.1.2 体温 试验前及试验后,温度(试验前:$F_{1,24}$ = 0.038,P>0.05;试验后:$F_{1,24}$ = 3.899,P>0.05)、光周期(试验前:$F_{1,24}$ = 4.234,P>0.05;试验后:$F_{1,24}$ = 2.359,P>0.05)及其交互作用(试验前:$F_{1,24}$ = 1.581,P>0.05;试验后:$F_{1,24}$ = 2.324,P>0.05)对白头鹎体温均无明显的影响(表1).

2.2 温度和光周期对白头鹎能量收支的影响

2.2.1 摄入能 试验前各组间白头鹎的摄入能没有明显差异(温度:$F_{1,23}$ = 0.010,P>0.05;光周期:$F_{1,23}$ = 1.201,P>0.05;交互作用:$F_{1,23}$ = 0.812,P>0.05).试验结束后(第28天),温度、光周期及温度和光周期的交互作用对白头鹎的摄入能有显著影响(温度:$F_{1,23}$ = 122.595,P<0.05;光周期:$F_{1,23}$ = 4.437,P<0.05;交互作用:$F_{1,23}$ = 12.511,P<0.05).低温短光组白头鹎的摄入能分别比暖温长光组、暖温短光组和低温长光组增加54%、83%和25%(表1).

2.2.2 排泄能 试验前各组间白头鹎的排泄能没有明显变化(温度:$F_{1,23}$ = 0.013,P>0.05;光周期:$F_{1,23}$ = 1.926,P>0.05;交互作用:$F_{1,23}$ = 0.849,P>0.05).适应第28天,白头鹎的排泄能明显受到温度及温度与光周期交互作用的影响(温度:$F_{1,23}$ = 72.713,P<0.05;交互作用:$F_{1,23}$ = 5.194,P<0.05),光周期对白头鹎排泄能的影响不显著($F_{1,23}$ = 0.007,P>0.05).低温短光组白头鹎的排泄能分别比暖温长光组、暖温短光组和低温长光组高108%、147%和19%(表1).

2.2.3 同化能 白头鹎的同化能在试验前没有明显变化(温度:$F_{1,23}$ = 0.003,P>0.05;光周期:$F_{1,23}$ = 0.103,P>0.05;交互作用:$F_{1,23}$ = 0.454,P>0.05).第28天白头鹎的同化能明显受到温度、光周期及温度与光周期交互作用的影响(温度:$F_{1,23}$ = 74.182,P<0.05;光周期:$F_{1,23}$ = 13.278,P<0.05;交互作用:$F_{1,23}$ = 10.723,P<0.05).低温短光组白头鹎的同化能为4组中的最大值,分别比暖温长光组、暖温短光组和低温长光组高67%、57%和29%(表1).

2.2.4 同化率 试验前各组间白头鹎的同化率没有明显差异(温度:$F_{1,23}$ = 0.058,P>0.05;光周期:$F_{1,23}$ = 2.861,P>0.05;交互作用:$F_{1,23}$ = 0.840,P>0.05).试验结束后白头鹎的同化率显著受温度和光周期的影响(温度:$F_{1,23}$ = 17.330,P<0.05;光周期:$F_{1,23}$ = 7.688,P<0.05),温度和光周期的交互作用对白头鹎的同化率影响不显著($F_{1,23}$ = 0.741,P>0.05)(表1).

2.3 温度和光周期对白头鹎消化道形态特征的影响

2.3.1 胃 从表2可以看出,白头鹎胃的长度明显受温度的影响($F_{1,23}$ = 21.531,P<0.05),而光周期及

表2 温度和光周期对白头鹎消化道形态的影响

Table 2 Effects of temperature and photoperiod acclimation on digestive tract morphology in Chinese bulbuls (mean±SE, n=7)

温度 Temperature	光周期 Photoperiod	胃 Stomach				小肠 Small intestine			
		Ⅰ	Ⅱ	Ⅲ	Ⅳ	Ⅰ	Ⅱ	Ⅲ	Ⅳ
暖温 Warm temperature	L	1.83±0.06b	418.97±82.57b	370.87±39.48b	108.49±9.23b	11.24±0.53	1177.50±150.56b	834.44±126.23c	191.21±28.98c
	S	1.81±0.05b	487.46±90.42b	411.90±78.26b	126.20±24.03b	12.07±0.48	1480.41±499.55ab	1066.10±378.22bc	242.96±77.55bc
低温 Cold temperature	L	2.16±0.05a	651.18±144.07a	517.33±61.74a	148.04±22.63a	11.90±0.48	1789.49±596.41a	1200.10±281.17ab	269.80±66.53ab
	S	2.06±0.07a	589.44±186.01ab	466.23±40.96ab	137.90±13.64ab	13.28±0.59	2035.03±325.93a	1504.37±212.47a	358.80±58.32a
显著性 Significance		T*	T*	T*, T×P*	T*, T×P*	ns	T*	T*	T*

温度 Temperature	光周期 Photoperiod	直肠 Rectum				总消化道 Total digestive tract			
		Ⅰ	Ⅱ	Ⅲ	Ⅳ	Ⅰ	Ⅱ	Ⅲ	Ⅳ
暖温 Warm temperature	L	1.53±0.12	142.31±43.29b	114.60±23.84b	34.02±9.35	14.60±0.58b	1738.79±234.37b	1329.91±166.35c	333.74±38.75c
	S	1.57±0.11	164.54±50.45b	122.90±26.32b	37.86±12.43	15.45±0.52ab	2132.41±612.88ab	1600.90±428.20bc	407.01±95.21bc
低温 Cold temperature	L	1.60±0.11	209.34±55.63ab	143.80±32.88ab	35.36±9.97	15.67±0.52ab	2650.01±723.43a	1861.23±322.98ab	453.20±85.55ab
	S	1.73±0.13	211.73±41.37a	156.64±26.61a	46.51±9.90	17.07±0.63a	2743.11±603.98a	2127.24±201.30a	543.21±52.38a
显著性 Significance		ns	T*	T*	ns	T*	T*	T*	T*

Ⅰ:长度 Length (cm);Ⅱ:含内容物质量 Wet mass with content (mg);Ⅲ:鲜质量 Wet mass (mg);Ⅳ:干质量 Dry mass (mg).组间胃、小肠、直肠及总消化道差异采用双因素协方差分析(two-way ANCOVA)(体质量为协变量) Stomach, small intestine, rectum and total digestive tract among different groups were used two-way ANCOVA with body mass as a covariate. Total digestive tract length, wet mass with content. 总消化道全长、含内容物质量、湿质量和干质量分别为胃、小肠和直肠的长度、含内容物质量、湿质量和干质量的总和 The wet mass and dry mass are the sum of stomach, small intestine and rectum length, wet mass with content, wet mass and dry mass, respectively. 下同 The same below.

温度和光周期的交互作用对白头鹎胃的长度影响不显著(光周期：$F_{1,23}=0.927, P>0.05$；交互作用：$F_{1,23}=0.474, P>0.05$)．胃的含内容物质量、鲜质量及干质量均受温度显著影响(含内容物质量：$F_{1,23}=6.518, P<0.05$；鲜质量：$F_{1,23}=12.604, P<0.05$；干质量：$F_{1,23}=7.731, P<0.05$)；胃的鲜质量及干质量受温度和光周期的交互作用影响显著(鲜质量：$F_{1,23}=5.507, P<0.05$；干质量：$F_{1,23}=4.326, P<0.05$)；而光周期对胃的含内容物质量、鲜质量及干质量影响不显著(含内容物质量：$F_{1,23}=0.063, P>0.05$；鲜质量：$F_{1,23}=0.430, P>0.05$；干质量：$F_{1,23}=0.006, P>0.05$)．回归分析表明，白头鹎胃的长度、含内容物质量、鲜质量及干质量与体质量相关不显著(表 3)．残差分析表明，白头鹎胃的长度、含内容物质量、鲜质量及干质量与摄入能和同化能不相关(表 4)．

2.3.2 小肠　温度、光周期及其交互作用对白头鹎小肠的长度均没有显著影响(温度：$F_{1,23}=2.894, P>0.05$；光周期：$F_{1,23}=3.838, P>0.05$；交互作用：$F_{1,23}=0.320, P>0.05$)．温度对小肠的含内容物质量、鲜质量及干质量影响显著(含内容物质量：$F_{1,23}=7.470, P<0.05$；鲜质量：$F_{1,23}=8.801, P<0.05$；干质量：$F_{1,23}=11.002, P<0.05$)，而光周期及温度和光周期的交互作用对小肠的含内容物质量(光周期：$F_{1,23}=1.236, P>0.05$；交互作用：$F_{1,23}=0.086, P>0.05$)、鲜质量(光周期：$F_{1,23}=3.068, P>0.05$；交互作用：$F_{1,23}=0.031, P>0.05$)及干质量(光周期：$F_{1,23}=4.072, P>0.05$；交互作用：$F_{1,23}=0.430, P>0.05$)影响均不显著(表 2)．回归分析表明，白头鹎的小肠除长度外，含内容物质量、鲜质量及干质量与体质量相关显著(表 3)．残差分析表明，白头鹎小肠的长度、鲜质量及干质量与摄入能相关；小肠的长度及干质量与同化能相关，表明白头鹎小肠长度和质量的增加可以提高白头鹎的摄食和消化能力(表 4)．

2.3.3 直肠　温度、光周期及其交互作用对白头鹎直肠的长度均没有显著影响(温度：$F_{1,23}=0.901, P>0.05$；光周期：$F_{1,23}=0.474, P>0.05$；交互作用：$F_{1,23}=0.123, P>0.05$)．温度对直肠的含内容物质量和鲜质量有显著影响(含内容物质量：$F_{1,23}=5.766, P<0.05$；鲜质量：$F_{1,23}=5.225, P<0.05$)，对直肠的干质量影响不显著($F_{1,23}=0.444, P>0.05$)．光周期及温度和光周期的交互作用对直肠的含内容物质量(光周期：$F_{1,23}=0.073, P>0.05$；交互作用：$F_{1,23}=0.416, P>0.05$)、鲜质量(光周期：$F_{1,23}=0.307, P>0.05$；交互作用：$F_{1,23}=0.009, P>0.05$)及干质量(光周期：$F_{1,23}=1.342, P>0.05$；交互作用：$F_{1,23}=0.529, P>0.05$)影响均不显著(表 2)．回归分析表明，白头鹎的直肠除长度外，含内容物质量、鲜质量及干质量与体质量显著相关(表 3)．残差分析表明，白头鹎直肠的长度、含内容物质量、鲜质量及干质量与摄入能和同化能无显著相关关系(表 4)．

表 3　白头鹎消化道器官对体质量的异速增长方程

Table 3　Allometric regressions of log digestive tract on log body mass for Chinese bulbuls ($\lg Y=\lg a+b\lg X$)

器官 Regression	参数 Parameter	a	b	r^2	P
胃	Ⅰ	0.05	0.17	0.034	>0.05
Stomach	Ⅱ	1.43	0.90	0.120	>0.05
	Ⅲ	1.76	0.62	0.127	>0.05
	Ⅳ	1.25	0.61	0.127	>0.05
小肠	Ⅰ	0.79	0.21	0.037	>0.05
Small intestine	Ⅱ	1.13	1.45	0.224	<0.05
	Ⅲ	0.63	1.69	0.326	<0.05
	Ⅳ	0.05	1.66	0.296	<0.05
直肠	Ⅰ	0.06	1.10	0.004	>0.05
Rectum	Ⅱ	0.64	1.13	0.149	<0.05
	Ⅲ	0.83	0.91	0.162	<0.05
	Ⅳ	0.02	1.19	0.153	<0.05
总消化道	Ⅰ	0.93	0.19	0.043	>0.05
Total	Ⅱ	1.50	1.31	0.226	<0.05
digestive	Ⅲ	1.31	1.34	0.329	<0.05
tract	Ⅳ	0.80	1.28	0.311	<0.05

表 4　白头鹎消化道器官对摄入能和同化能的最小二乘线性残差分析

Table 4　Log digestive tract residuals versus log gross energy intake residuals, or log digestive tract residuals versus log digestible energy intake residuals for Chinese bulbuls

器官 Regression	参数 Parameter	摄入能 GEI			同化能 DEI		
		b	r^2	P	b	r^2	P
胃	Ⅰ	−0.12	0.006	>0.05	0.10	0.003	>0.05
Stomach	Ⅱ	−0.07	0.002	>0.05	−0.11	0.047	>0.05
	Ⅲ	−0.14	0.032	>0.05	−0.12	0.023	>0.05
	Ⅳ	−0.17	0.063	>0.05	−0.17	0.046	>0.05
小肠	Ⅰ	0.37	0.158	<0.05	0.54	0.301	<0.05
Small	Ⅱ	0.11	0.063	>0.05	0.03	0.004	>0.05
intestine	Ⅲ	0.21	0.221	<0.05	0.16	0.101	>0.05
	Ⅳ	0.20	0.236	<0.05	0.17	0.166	<0.05
直肠	Ⅰ	0.05	0.005	>0.05	0.09	0.022	>0.05
Rectum	Ⅱ	0.06	0.021	>0.05	−0.03	0.005	>0.05
	Ⅲ	0.09	0.032	>0.05	0.07	0.014	>0.05
	Ⅳ	0.10	0.068	>0.05	0.06	0.018	>0.05
总消化道	Ⅰ	0.62	0.309	<0.05	0.61	0.267	<0.05
Total	Ⅱ	0.09	0.038	>0.05	0.01	0.001	>0.05
digestive	Ⅲ	0.24	0.157	<0.05	0.18	0.073	>0.05
tract	Ⅳ	0.22	0.138	<0.05	0.19	0.196	<0.05

2.3.4 总消化道　白头鹎的总消化道长度、含内容物质量、鲜质量及干质量均受温度显著影响(长度：$F_{1,23}=5.076$, $P<0.05$；含内容物质量：$F_{1,23}=9.055$, $P<0.05$；鲜质量：$F_{1,23}=12.704$, $P<0.05$；干质量：$F_{1,23}=713.197$, $P<0.05$)(表 2).光周期及温度和光周期的交互作用对白头鹎的总消化道长度(光周期：$F_{1,23}=3.450$, $P>0.05$；交互作用：$F_{1,23}=0.276$, $P>0.05$)、含内容物质量(光周期：$F_{1,23}=0.695$, $P>0.05$；交互作用：$F_{1,23}=0.384$, $P>0.05$)、鲜质量(光周期：$F_{1,23}=2.237$, $P>0.05$；交互作用：$F_{1,23}=0.720$, $P>0.05$)及干质量(光周期：$F_{1,23}=4.402$, $P>0.05$；交互作用：$F_{1,23}=0.061$, $P>0.05$)影响均不显著(表 2).回归分析表明,白头鹎的总消化道除长度外,含内容物质量、鲜质量及干质量与体质量相关显著(表 3).残差分析表明,白头鹎总消化道的长度、鲜质量及干质量与摄入能相关；总消化道的长度及干质量与同化能相关,表明白头鹎总消化道长度和质量的增加有利于白头鹎的摄食和吸收能力的提高(表 4).

3 讨　论

低温、短光及食物质量的降低等诸多严峻条件是动物面对冬季的重要挑战,动物可以通过调整形态、生理和生化指标等一系列策略来适应可变的外界环境[34,43-44].本研究表明,温度和光周期及其交互作用影响白头鹎体质量和能量收支,同时温度影响消化道器官的长度与质量,而光周期和温度与光周期的交互作用(胃除外)对消化道形态的影响不显著.

3.1 温度和光周期对白头鹎体质量的影响

鸟类的体质量受许多环境因子的影响,如温度、光照、食物的质和量及鸟类自身的生理状态等,体质量已成为衡量鸟类生存代价(living costs)的重要指标之一[9,13,44].鸟类在面临诸多外界因素及自身生理状态改变等条件下,体质量会相应发生改变以满足自身生存需要[11,45-47].本试验结果显示,温度和光周期对白头鹎体质量有明显的影响,低温短光组白头鹎的体质量分别比暖温长光组、暖温短光组和低温长光组高 20%、13%和 13%(表 1),与之前的报道一致,即冬季及低温条件下白头鹎体质量显著提高[34,39-40].自然条件下,由于冬季食物缺乏、气候寒冷等原因,动物需储存能量以应对恶劣的环境[2,13,48].本试验结果表明,虽然白头鹎在短光照与低温共同存在的驯化条件下表现出更高的体质量水平,却未发现光周期与温度交互作用对白头鹎体质量的明显影响,推测短光照与低温协同作用对白头鹎冬季体质量增加的影响可能存在,但是这种作用的显现可能依赖于其他环境因素的水平.而这一点也有待进一步探究,以更好地了解鸟类体质量的季节性适应及机理[47-49].

3.2 温度和光周期对白头鹎能量收支的影响

对于动物来说,其能量摄入、处理及其分配速率与效率会直接影响动物的生存能力,在低温胁迫中增加能量的摄入来补偿能量消耗对其生存至关重要[8,50-53].如低温组(10 ℃)白头鹎的摄入能和同化能分别比暖温组(30 ℃)增加 53%和 55%[23].而在季节性驯化中也表现出类似的结果.Wu 等[13]发现,冬季白头鹎的摄入能和同化能分别是夏季的 1.2 和 1.3 倍.本研究发现,低温条件下白头鹎摄入能、排泄能及同化能在整体驯化过程中均显著高于暖温组个体,表明低温是促使白头鹎能量摄入增加的重要原因.另外,本研究发现光周期也是影响白头鹎能量收支的重要因子,证实了倪小英等[20]的研究结论.同时还发现,光周期与温度交互作用对白头鹎能量收支影响显著,其中,低温加短光照促使白头鹎表现出最大的能量需求,从而具有最大的摄入能与同化能.可见,较高的摄入能和同化能可能是白头鹎适应低温、短光照等冬季环境的能量需求的重要对策.本次试验还发现,暖温组的同化率显著高于低温组.推测尽管低温组消化道质量有所增加,可以容纳更多的食物,但摄食量增加将缩短食物在消化道内的滞留时间(retention time),从而使同化率降低[14,16,54-56].

3.3 温度和光周期对白头鹎消化道形态的影响

动物的消化道是对外界环境反映较为敏感的器官之一,具有高度的可塑性[4-5,56].大量研究证明了鸟类消化道器官的可塑性,并且低温及冬季环境条件下鸟类消化道在长度或质量上有所增加[13,23,57-59].本试验与上述研究结果相符,温度、光周期及其交互作用影响消化道长度与质量,其中温度的影响最为明显.低温条件下白头鹎的胃、小肠及总消化道的质量及长度总体上都较暖温条件下个体高,这一结果与之前的温度试验结果一致[23].有些器官如胃、小肠及总消化道等的质量或长度差异达到显著水平,表明白头鹎消化道器官应环境改变而发生相应的适应性变化,其中低温下白头鹎为适应增加的摄食量,获取更多的能量,增加消化道容积以延长食物滞留时间来提高消化率,满足自身能量的需求,同时也证实了消化道器官的表型可塑性.在低温胁迫下,能量需求增加,必然需要增加摄入能和同

化能才能维持自身的能量平衡[23].为了满足代谢需求,鸟类可能依赖于胃肠道形态的改变来增加消化道容积和质量,促使动物在消化道形态结构上进行一些有益的调节[5,14].本试验结果证明了这一观点,体质量与消化道的异速增长方程显示,小肠、直肠和总消化道质量与白头鹎体质量显著相关(表 3).残差分析表明,小肠长度、鲜干质量和和总消化道长度、干质量与摄入能和同化能显著相关(表 4),体现了消化道可塑性对能量收支的响应.

总之,光周期与温度影响了白头鹎的体质量及能量收支,是白头鹎体质量及能量收支表现出季节性差异的重要环境因子.其中低温是白头鹎冬季体质量和能量收支达到最大值的主要原因;短光照主要作为能量摄入变化的环境信号;低温与短光照可能存在交互作用促使白头鹎在冬季具有更高的体质量及能量代谢水平.同时,低温促进白头鹎胃、小肠及总消化道的长度和质量明显增加,更深层的原因可能在于肌肉层的加厚及粘膜层上皮细胞的改变等[16,58],还有待于今后进一步研究.

致谢　感谢温州大学生命与环境科学学院动物生理生态组的全体成员.

参考文献

[1] Piersma T, Lindström A. Rapid reversible changes in organ size as a component of adaptive behaviour. *Trends in Ecology & Evolution*, 1997, **12**: 134-138

[2] Sanitjan S, Chen J (陈　进), Wang B (王　博). Comparison of two plant-birds mutualistic systems in Asian tropical rainforests. *Chinese Journal of Applied Eco-logy* (应用生态学报), 2011, **22**(6): 1579-1584 (in Chinese)

[3] O'Connor TP. Metabolic characteristics and body composition in House Finches: Effects of seasonal acclimatization. *Journal of Comparative Physiology B*, 1995, **165**: 298-305

[4] Piersma T, Drent J. Phenotypic flexibility and the evolution of organismal design. *Trends in Ecology & Evolution*, 2003, **18**: 228-233

[5] Xu X-J (徐兴军), Lv J-W (吕建伟), Huan L-F (禤立芳), *et al*. Genetic polymorphism of blood protein of six *Passeriforms* species in Zhalong National Nature Reserve. *Chinese Journal of Applied Ecology* (应用生态学报), 2009, **20**(6): 1465-1470 (in Chinese)

[6] Zheng WH, Lin L, Liu JS, *et al*. Physiological and biochemical thermoregulatory responses of Chinese bulbuls *Pycnonotus sinensis* to warm temperature: Phenotypic flexibility in a small passerine. *Journal of Thermal Biology*, 2013, **38**: 240-246

[7] Zheng WH, Li M, Liu JS, *et al*. Seasonal variation of metabolic thermogenesis in Eurasian tree sparrows (*Passer montanus*) over a latitudinal gradient. *Physiological & Biochemical Zoology*, 2014, **87**: 704-718

[8] Hegemann A, Matson KD, Versteegh MA, *et al*. Wild skylarks seasonally modulate energy budgets but maintain energetically costly inflammatory immune responses throughout the annual cycle. *PLoS One*, 2012, **7**(5): e36358

[9] Cooper SJ. Daily and seasonal variation in body mass and visible fat in mountain chickadees and juniper titmice. *Wilson Journal of Ornithology*, 2007, **119**: 720-724

[10] Liu JS, Li M. Phenotypic flexibility of metabolic rate and organ masses among tree sparrows *Passer montanus* in seasonal acclimatization. *Acta Zoologica Sinica*, 2006, **52**: 469-477

[11] Liu J-S (柳劲松), Li M (李　铭), Shao S-L (邵淑丽). Seasonal changes in thermogenic properties of liver and muscle in tree sparrows *Passer montanus*. *Acta Zoologica Sinica* (动物学报), 2008, **54**(5): 777-784 (in Chinese)

[12] Lou Y, Yu TL, Huang CM, *et al*. Seasonal variations in the energy budget of Elliot's pheasant (*Syrmaticus ellioti*) in cage. *Zoological Research*, 2013, **34**: 19-25

[13] Wu MS, Xiao YC, Yang F, *et al*. Seasonal variation in body mass and energy budget in Chinese bulbuls (*Pycnonotus sinensis*). *Avian Research*, 2014, **5**: 1-10

[14] Karasov WH. Digestive physiology: A view from molecules to ecosystem. *American Journal of Physiology*, 2011, **301**: 276-284

[15] Pierce BJ, McWilliams SR. Seasonal changes in composition of lipid stores in migratory birds: Causes and consequences. *Auk*, 2005, **107**: 269-279

[16] Karasov WH, Martínez del Rio C, Caviedes-Vidal E. Ecological physiology of diet and digestive systems. *Annual Review of Physiology*, 2011, **73**: 69-93

[17] Arens JR, Cooper SJ. Metabolic and ventilatory acclimatization to cold stress in house sparrows *Passer domesticus*. *Physiological & Biochemical Zoology*, 2005, **78**: 579-589

[18] Lindsay CV, Downs CT, Brown M. Physiological variation in Amethyst sunbirds (*Chalcomitra amethystina*) over an altitudinal gradient in winter. *Journal of Experimental Biology*, 2009, **212**: 483-493

[19] Lindsay CV, Downs CT, Brown M. Physiological variation in Amethyst sunbirds (*Chalcomitra amethystina*) over an altitudinal gradient in summer. *Journal of Thermal Biology*, 2009, **34**: 190-199

[20] Ni X-Y (倪小英), Lin L (林　琳), Zhou F-F (周菲菲), *et al*. Effects of photoperiod on body mass, organ masses and energy metabolism in Chinese bulbul (*Pycnonotus sinensis*). *Acta Ecologica Sinica* (生态学报), 2011, **31**(6): 1703-1713 (in Chinese)

[21] Webster MD, Weathers WW. Seasonal changes in energy and water use by verdins, *Auriparus flaviceps*. *Journal of Experimental Biology*, 2000, **203**: 3333-3344

[22] Guillemette M, Butler PJ. Seasonal variation in energy expenditure is not related to activity level or water tem-

perature in a large diving bird. *Journal of Experimental Biology*, 2012, **215**: 3161-3168
[23] Wu YN, Lin L, Xiao YC, *et al*. Effects of temperature acclimation on body mass and energy budget in the Chinese bulbul *Pycnonotus sinensis*. *Zoological Research*, 2014, **35**: 33-41
[24] Kendeigh SC. Effect of temperature and season on energy resources of the English sparrow. *Auk*, 1945, **66**: 766-775
[25] Kvist A, Lindström Å. Gluttony in migratory waders: Unprecedented energy assimilation rates in vertebrates. *Oikos*, 2003, **103**: 397-402
[26] Stokkan KA, Mortensen A, Blix AS. Food intake, feeding rhythm, and body mass regulation in Svalbard rock ptarmigan. *American Journal of Physiology*, 1986, **251**: 264-267
[27] Moore CB, Siopes TD. Effects of lighting conditions and melatonin supplementation on the cellular and humoral immune responses in Japanese quail *Coturnixcoturnix japonica*. *General & Comparative Endocrinology*, 2000, **119**: 95-104
[28] Dawson A, Sharp PJ. Photorefractoriness in birds-photoperiodic and non-photoperiodic control. *General & Comparative Endocrinology*, 2007, **153**: 378-384
[29] Yang Z-H (杨志宏), Shao S-L (邵淑丽), Liu J-S (柳劲松). Effect of temperature and photoperiod acclimation on digestive tract morphology and energy budget of tree sparrows (*Passer montanus*). *Chinese Journal of Ecology* (生态学杂志), 2010, **29**(2): 344-350 (in Chinese)
[30] Swanson Dl, Zhang YF, Liu JS, *et al*. Relative roles of temperature and photoperiod as drivers of metabolic flexibility in dark-eyed juncos. *Journal of Experimental Biology*, 2014, **217**: 866-875
[31] Pang B-Z (庞秉璋). Food habits of Chinese bulbul (*Pycnonotus sinensis*). *Chinese Journal of Zoology* (动物学杂志), 1981, **16**(4): 75-76 (in Chinese)
[32] Li D-L (李东来), Ding Z-J (丁振军), Yin J-X (殷江霞), *et al*. The distribution of Chinese bulbuls (*Pycnonotus sinensis*) dispersed to Shenyang. *Chinese Journal of Zoology* (动物学杂志), 2013, **48**(1): 74 (in Chinese)
[33] Zheng WH, Liu JS, Jiang XH, *et al*. Seasonal variation on metabolism and thermoregulation in Chinese bulbul. *Journal of Thermal Biology*, 2008, **33**: 315-319
[34] Zheng WH, Liu JS, Swanson DL. Seasonal phenotypic flexibility of body mass, organ masses, and tissue oxidative capacity and their relationship to RMR in Chinese bulbuls. *Physiological & Biochemical Zoology*, 2014, **87**: 432-444
[35] Zhou W (周 围), Wang Y-P (王玉萍), Chen D-H (陈德汉), *et al*. Diurnal rhythms of Chinese bulbul (*Pycnonotus sinensis*) body temperature, body mass, and energy metabolism. *Chinese Journal of Ecology* (生态学杂志), 2010, **29**(12): 2395-2400 (in Chinese)
[36] Peng L-J (彭丽洁), Tang X-L (唐小丽), Liu J-S (柳劲松), *et al*. The effects of thyroid hormone on basal thermogenesis in Chinese bulbul (*Pycnonotus sinensis*). *Acta Ecologica Sinica* (生态学报), 2010, **30**(6): 1500-1507 (in Chinese)
[37] Xia S-S (夏素素), Yang F (杨 芳), Wang R-M (王润梅), *et al*. Physiological responses in Chinese bulbuls to seasonal acclimatization and temperature acclimation. *Acta Ecologica Sinica* (生态学报), 2015, **35**(7): 2349-2359 (in Chinese)
[38] Lin L (林 琳), Cao M-T (曹梦婷), Hu Y-L (胡益林), *et al*. Effect of environmental temperature on thermogenesis and evaporative water loss in Chinese bulbuls (*Pycnonotus sinensis*). *Acta Ecologica Sinica* (生态学报), 2014, **34**(3): 564-571 (in Chinese)
[39] Zheng W-H (郑蔚虹), Fang Y-Y (方媛媛), Jiang X-H (姜雪华), *et al*. Comparison of thermogenic character of liver and muscle in Chinese bulbul *Pycnonotus sinensis* between summer and winter. *Zoological Research* (动物学研究), 2010, **31**(3): 319-327 (in Chinese)
[40] Zhang G-K (张国凯), Fang Y-Y (方媛媛), Jiang X-H (姜雪华), *et al*. Adaptive plasticity in metabolic rate and organ masses among *Pycnonotus sinensis*, in seasonal acclimatization. *Chinese Journal of Zoology* (动物学杂志), 2008, **43**(4): 13-19 (in Chinese)
[41] Wang D, Sun R, Wang Z, *et al*. Effects of temperature and photoperiod on thermogenesis in plateau pikas (*Ochotona curzoniae*) and root voles (*Microtus oeconomus*). *Journal of Comparative Physiology B*, 1999, **169**: 77-83
[42] Grodzinski W, Wunder BA. Ecological energetics of small mammals// Golley FB, Petrusewicz K, Ryszkowski L, eds. Small Mammals: Their Productivity and Population Dynamics. Cambridge: Cambridge University Press, 1975: 173-204
[43] Swanson DL. Cold hardiness and summit metabolism in North American kinglets during fall migration. *Acta Zoologica Sinica*, 2007, **53**: 600-606
[44] Zheng WH, Li M, Liu JS, *et al*. Seasonal acclimatization of metabolism in Eurasian tree sparrows (*Passer montanus*). *Comparative Biochemistry & Physiology Part A: Molecular & Integrative Physiology*, 2008, **151**: 519-525
[45] Williams JB, Tieleman BI. Flexibility in basal metabolic rate and evaporative water loss among hoopoe larks exposed to different environmental temperatures. *Journal of Experimental Biology*, 2000, **203**: 3153-3159
[46] Chamane SC, Downs CT. Seasonal effects on metabolism and thermoregulation abilities of the red-winged starling (*Onychognathus morio*). *Journal of Thermal Biology*, 2009, **34**: 337-341
[47] Vézina F, Petit M, Buehler DM, *et al*. Limited access to food and physiological trade-offs in a long-distance migrant shorebird. I. Energy metabolism, behavior, and body-mass regulation. *Physiological & Biochemical Zoology*, 2009, **82**: 549-560
[48] Liknes ET, Swanson DL. Seasonal variation in cold tolerance, basal metabolic rate, and maximal capacity for thermogenesis in white breasted nuthatches *Sitta car-*

olinensis and downy woodpeckers *Picoides pubescens*, two unrelated arboreal temperate residents. *Journal of Avian Biology*, 1996, **27**: 279-288

[49] McNab BK. Ecological factors affect the level and scaling of avian BMR. *Comparative Biochemistry & Physiology Part A: Molecular & Integrative Physiology*, 2009, **152**: 22-45

[50] Zhao ZJ, Wang DH. Plasticity in the physiological energetics of Mongolian gerbils is associated with diet quality. *Physiological & Biochemical Zoology*, 2009, **82**: 504-515

[51] Yang Z-H (杨志宏), Shao S-L (邵淑丽). The influence of different food qualities on the energy budget and digestive tract morphology of tree sparrows *Passer montanus*. *Acta Ecologica Sinica* (生态学报), 2011, **31**(4): 3937-3946 (in Chinese)

[52] Yang Z-H (杨志宏), Wu Q-M (吴庆明), Dong H-Y (董海燕), *et al*. The energy budget of tree sparrows *Passer montanus* in wind different speed and duration. *Acta Ecologica Sinica* (生态学报), 2013, **33**(19): 6028-6034 (in Chinese)

[53] Cain BW. Effect of temperature on energy requirements and northward distribution of the black-bellied tree duck. *The Wilson Bulletin*, 1973, **85**: 308-317

[54] Gross JE, Wang ZW, Wunder BA. Effects of food quality and energy needs: Changes in gut morphology and capacity of *Microtus ochrogaster*. *Journal of Mammalogy*, 1985, **66**: 661-667

[55] McWilliams SR, Karasov WH. Phenotypic flexibility in digestive system structure and function in migratory birds and its ecological significance. *Comparative Biochemistry & Physiology Part A: Molecular & Integrative Physiology*, 2001, **128**: 579-593

[56] Zheng WH, Lin L, Liu JS, *et al*. Geographic variation in basal thermogenesis in little buntings: Relationship to cellular thermogenesis and thyroid hormone concentrations. *Comparative Biochemistry & Physiology Part A: Molecular & Integrative Physiology*, 2013, **164**: 483-490

[57] Tieleman BI, Williams JB, Buschur ME, *et al*. Phenotypic variation of larks along an aridity gradient: Are desert birds more flexible? *Ecology*, 2003, **84**: 1800-1815

[58] Lv JW, Sun YR, Sun CR, *et al*. Seasonal plasticity of duodenal morphology and histology in *Passer montanus*. *Zoomorphology*, 2014, **133**: 435-443

[59] Wu M-S (吴梦斯), Zhao L-D (赵丽丹), Wang R-M (王润梅), *et al*. Comparison of energy budget and digestive tract morphology in Hwamei *Garrulax canorus* between winter and summer. *Chinese Journal of Ecology* (生态学杂志), 2015, **34**(4): 1031-1037 (in Chinese)

作者简介　王润梅, 女, 1994 年生.主要从事鸟类能量学研究. E-mail: 2364509687@qq.com

责任编辑　肖　红

王润梅, 吴玉南, 梁洪基, 等. 温度与光周期对白头鹎体质量、能量收支和消化道形态的影响. 应用生态学报, 2016, **27**(6): 1959-1967

Wang R-M, Wu Y-N, Liang H-J, *et al*. Effects of temperature and photoperiod on body mass, energy budget and digestive tract morphology in *Pycnonotus sinensis*. *Chinese Journal of Applied Ecology*, 2016, **27**(6): 1959-1967 (in Chinese)