文章编号:1000-0615(2007)01-0031-07

Effect of water current and temperature on growth of juvenile *Acipenser baeri*

HUANG Ning-yu, CHENG Qi-qun, GAO Lu-jiao, YAO Zong-li, XIA Lian-jun

(*Key Laboratory of Marine and Estuarine Fisheries Certificated by the Ministry of Agriculture, East China Sea Fisheries Research Institute, Chinese Academy of Fishery Sciences, Shanghai* 200090, *China*)

Abstract: Effect of water current and temperature on growth of juvenile sturgeon *Acipenser baeri* in intensive indoor (semi-recirculating) tank culture was investigated in a 90-day rearing trial. Fish were reared in continuous water current with three levels of velocity of 0.12 (V_1), 0.16 (V_2) and 0.20 m·s^{-1} (V_3) respectively, and isochronic water current (in half an hour with a velocity of 0.20 m·s^{-1}, then in the next half an hour of intermission with a velocity of 0 m·s^{-1}) (V_4), under water temperature varying between 13.8 ℃ and 24.7 ℃. Within a range of water temperature of 16.7 - 22.5 ℃, growth efficiency (*GE*) and daily growth rate (*DGR*) increased with the increase of velocity of water current, and maximum DGR occurred in V_3 group. There was significant positive linear relation between *GE* and *V*: $GE = 52.5\ V + 69.567$ ($R^2 = 0.997$, $P < 0.05$), when the velocity of water current ranged from 0.12 m·s^{-1} to 0.20 m·s^{-1}. In contrast, within a range of water temperature of 13.8 - 16.7 ℃ or 22.5 - 24.7 ℃, *DGR* of V_3 group were lower than that of V_1 and V_2 groups. Fish in the group with intermission of non-water current obtained the highest *GE* while lowest *FCR* at a water temperature of 20.7 ℃. It suggested that water current and water temperature have reciprocal effect on the growth of juvenile sturgeon *A. baeri*. The fish has different optimal water temperatures at different velocity of water currents, and the optimum temperatures are between 20.2 ℃ and 20.7 ℃. This result suggests that group V_4 is the best among these groups that can produce better economic benefits.

Key words: *Acipenser baeri*; growth; intensive indoor (semi-recirculating) tank culture; current; temperature

CLC number: S 917.4; S 931.1 **Document code**: A

1 Introduction

Intensive indoor (semi-recirculating) tank culture is increasing recently in China, especially in the arid area of northwestern China on account of the shortage of freshwater resource. In this type of fish culture system, water is usually recycled; aeration is applied continuously to enhance dissolved oxygen and provide water circulation; water temperature is monitored and controlled throughout the whole culture period. The practical issue is how to strike a balance between sustaining large quantities of aquatic biomass and saving energy in operating this fish culture system. In order to acquire the fundamental data of management of the intensive indoor fish culture system, it is important to study

Received date: 2006-07-05

Foundation item: Supported by grants from Shanghai Agriculture Committee (2004-1-5-5)

Brief introduction of the author: HUANG Ning-yu (1963 -), male, born in Shanghai, Associate Professor. Research field: aquaculture. E-mail: ningyu886@hotmail.com

Corresponding author: CHENG Qi-qun, Tel: 021-65688139, E-mail: qiquncheng@gmail.com

the effect of water current and temperature on the growth of culture species of high-value table fish.

As a non-biological factor of fish living environments, water current can stimulate the sense organs of fishes, and make it produce corresponding activity manners and response mechanism. Some researchers considered that water current can stimulate the metabolism systems and has effect on the growth and development of fishes[1-3].

But others argued that water current is a masking factor contributing to retardation of fish growth. On the other hand, water temperature can control metabolism rate of fishes, and successively impacts the physiological and biochemical processes, such as ingestion, aspiration, as well as assimilation and catabolism of living materials of fish, thus it becomes a control factor in regulation of fish activity and growth [4-7].

Acipenser baeri is mainly distributed in all tributaries of River Ebi and River Kroma. In 1956, it was successfully introduced from River Ebi into River Pechora. From then on, *A. baeri* was introduced into Baltic sea and the Volga River systems, and natural populations came into being in these water systems[8]. In Xinjiang Autonomous Region of China, *A. baeri* appears occasionally in some rivers which link up into Europe, such as River Eqis, Bruent Sea and Lake Bosten[9]. There are three ecotypes of *A. baeri* in nature: semi-migration, river-resident and lake-river migration [10]. It suggests that *A. baeri* can be adapted to different water current and temperature, but how to affect the growth of *A. baeri*, there were no correlative researches up to the present. Purpose of this paper is to acquire the fundamental data about water current and temperature on the growth of juvenile *A. baeri*, which can direct and improve the technology of intensive indoor (semi-recirculating) tank culture of *A. baeri*. While *A. baeri* as a growing popular freshwater culture species, its aquaculture is increasing rapidly all over China in recent years[11-12].

2 Materials and methods

2.1 Experimental fish

Sturgeon *A. baeri* (50 – 80 mm) were obtained from Beijing Fisheries Institute (Beijing, China) on June 5, 2004. They were acclimatized to the experimental conditions for a period of 25 days in Haima Spring Base (Jiuquan City, Gansu Province, China), during which time they were fed a soft pellet feed compounded by ourselves in East China Sea Fisheries Research Institute (Shanghai, China). Strong and active *A. baeri* were selected, and the average body weight of the fish at the beginning of the experiment was (25.04 ± 1.85) g [standard length (SL) (220.02 ± 1.35) mm].

2.2 Experimental conditions

Groups of 1 500 fish were randomly allocated into each of 12 cement tanks (10 m × 10 m × 1.2 m with chip angles at circumferences and 110mm limber tube at the center) with three replicates per treatment of four velocities (V_1, V_2, V_3 and V_4) of water current.

The tanks were supplied with a mixture of filtered well water and bio-purified recycling water at 200 L · min^{-1} in a cycling purifying flow-through system. In addition, a probiotics *Rhodospirillaceae* RP. Sphaeroides (PSB, photosynthetic bacteria; East China Sea Fisheries Research Institute, Shanghai, China) was also added into rearing water to maintain water quality. The water temperature was not manipulated artificially either, varying at a range of 13.8 to 24.7 ℃ during the experimental period of 90 days (June 30 – Sep 28, 2004). Photoperiod cycle was not manipulated artificially, changing with variation of hours of sunlight seasonally.

Three tanks each were allocated to each water current treatment. Three velocities (0.12 m · s^{-1}, 0.16 m · s^{-1}, 0.20 m · s^{-1}) of continuous water current (groups V_1, V_2 and V_3) were provided and maintained with 0.55, 0.75 and 0.9 kW oxygen-enhancers; while in isochronic water current V_4

group (in half an hour with a velocity of 0.20 m · s^{-1}, then in the next half an hour of intermission with a velocity of 0 m · s^{-1}), a 0.9 kW oxygen enhancer and a 1.1 kW fan were used to provide water current and to enhance oxygen every 30 min alternatively. The dissolved oxygen during the rearing period was kept about (5.5 ± 0.5) mg · L^{-1}.

During the whole experimental period, pH, dissolved oxygen, and ammonia content in water were monitored, and all of them were maintained in the expected range. The activity of experimental fish was checked everyday. The ponds were disinfected by bromine (0.2 g · m^{-3}) every 15 days to prevent diseases.

Fish were hand-fed to satiation 6 times daily with soft pellet compounded for sturgeon produced by ourselves in East China Sea Fisheries Research Institute (Shanghai, China). The protein contents are 40% - 44%. The feed consumptions for each tank were recorded everyday.

2.3 Fish growth measurement

Fifty fish were sampled randomly for measurement of standard length (*SL*, mm) and body weight (*BW*, g) every 10 days. The growth performances of sturgeons were described as daily net weight gain (*DWG*, g · d^{-1}), net yield (*NY*, g · d^{-1}), daily growth rate (*DGR*, % · d^{-1}), feed conversion (*FC*, %) and growth efficiency (*GE*, %)[13]. The calculations of these parameters are as follows:

$$DWG = (W_2 - W_1)/[n(t_2 - t_1)]$$

$$NY = W_2/n - W_1/n$$

$$DGR(\%) = 100(\mathrm{Ln}W_2 - \mathrm{Ln}W_1)/(t_2 - t_1)$$

$$FC(\%) = F/(W_2 - W_1) \times 100$$

$$GE(\%) = 100(W_2 - W_1)/F$$

Where W_1 and W_2 are body weight (g) at initiating time (t_1) and ending time (t_2), F is the total food-taking (g) during the experimental period, and n is the number of fish in each experimental tank. Statistical analysis is performed using the statistical software, SPSS [14].

3 Results

3.1 Growth of *A. baeri* of each water current group at different temperature

DGR of fish in each water current group showed significant quadratic functional relationship with temperature (Tab. 1). The relationships between the *DGR* and water temperature were expressed by the following formula:

$SGR_{V_1} = -0.0563T^2 + 2.3083T - 19.902$ ($r^2 = 0.9366, P < 0.05$)

$SGR_{V_2} = -0.0632T^2 + 2.5839T - 22.30$ ($r^2 = 0.9674, P < 0.05$)

$SGR_{V_3} = -0.1182T^2 + 4.7635T - 43.295$ ($r^2 = 0.9026, P < 0.05$)

$SGR_{V_4} = -0.054T^2 + 2.2366T - 19.266$ ($r^2 = 0.9813$, $P < 0.05$)

Based on the regression formula, it was found that *DGR* of juvenile *A. baeri* in V_1 group showed the highest of 3.5764 (% · d^{-1}) at 20.5 ℃. It suggested that 20.5 ℃ may be the optimum temperature for juvenile *A. baeri* cultured in the water current velocity of 0.12 m · s^{-1} in the indoor intensive fish culture system. Similarly, the optimum temperature for fish in group V_2, V_3 and V_4 are 20.4 ℃, 20.2 ℃ and 20.7 ℃, respectively (Fig. 1). Fish in V_3 group showed the highest *DGR* only when the water temperature between 16.7 ℃

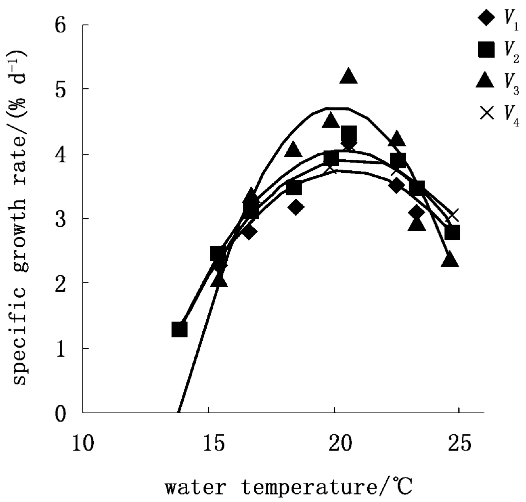

Fig. 1　Relationships between daily growth rate and water temperature under varied water currents

and 22.5 ℃. If the water temperature is between 23.3 and 24.7 ℃, or between 13.8 ℃ and 15.4 ℃, fish in V_3 group showed the lowest *DGR*.

3.2 Relationship between growth of *A. baeri* and velocity of water current

Growth performance and feeding conversion of *A. baeri* in different water current groups show some differences after being cultured for 90 days (Tab.2). From Tab.2, it is found that the final body weights of juvenile *A. baeri* in V_3 group(with velocity of 0.20 $m \cdot s^{-1}$) are significantly higher than V_1 group (with velocity of 0.12 $m \cdot s^{-1}$). At the same time, *DGR* and *NY* of V_3 group are 1.11 times and 1.36 times those of V_1 group, respectively. The feed conversion (*FC*) of fish in V_4 group (with velocity of 0.20 $m \cdot s^{-1}$) is the lowest among the four groups, and their growth efficiency (*GE*) is the highest. What's more, the *DGR* of this group has the tendency of increase than other groups at both higher temperature segment and lower temperature segment.

Tab.1 Daily growth Rate(*DGR*) of juvenile *A. baeri* of each group at different temperature

date	temperature (℃)	daily growth rate(*DGR*) (% · d^{-1})			
		V_1	V_2	V_3	V_4
June 30	24.3				
July 10	24.7	2.78	2.78	2.47	3.07
July 20	23.3	3.10	3.49	2.95	3.45
July 30	22.5	3.52	3.91	4.28	3.77
Aug. 9	20.6	4.16	4.34	5.20	4.15
Aug. 19	19.9	3.88	3.96	4.55	3.8
Aug. 29	18.4	3.20	3.48	4.07	3.46
Sept.8	16.7	2.77	3.12	3.36	3.11
Sept.18	15.4	2.29	2.48	2.06	2.32
Sept.28	13.8	1.34	1.31	1.03	1.36

Tab.2 Growth performance and feeding conversion of juvenile *Acipenser baeri* cultured in different velocity of water current for 90 days **(means ± SD)**

group	V_1	V_2	V_3	V_4
initial body weight (g)	25.0 ± 2.0	25.0 ± 1.7	25.0 ± 1.8	25.0 ± 1.7
finally body weight (g)	374.2 ± 2.5^a	441.1 ± 3.1^a	501.3 ± 3.4^b	432.1 ± 3.1^a
net yield (g)	349.2 ± 24.5^a	416.3 ± 27.5^a	476.2 ± 32.5^b	407.1 ± 21.5^a
daily weight gain (g)	3.9 ± 1.4^a	4.6 ± 1.5^a	5.3 ± 1.8^b	4.5 ± 1.3^a
average daily growth rate (% · d^{-1})	3.01 ± 0.2^a	3.2 ± 0.2^a	3.3 ± 0.2^a	3.2 ± 0.1^a
growth efficiency (%)	75.8 ± 1.4^a	78.1 ± 1.5^a	80.0 ± 1.6^a	82.0 ± 1.3^a
feed coefficent	1.3 ± 0.1^a	1.4 ± 0.1^a	1.3 ± 0.1^a	1.2 ± 0.1^a

Notes: The difference letters on the parameters in one row means significant differences($P < 0.05$)

Comparing the growth of juvenile *A. baeri* in three different groups V_1, V_2 and V_3(with velocity of water current between 0.12 $m \cdot s^{-1}$ and 0.20 $m \cdot s^{-1}$), it was found that the final body weight, body length, *GE*, *NY*, *DGR* and *DWG* of juvenile increased, while *FC* decreased with the increase of velocity of water current. *GE* of juvenile *A. baeri* and *V* showed significant positive correlated relationship (Fig.2). The relation formula is: $GE = 53.5V + 69.567$ ($r^2 = 0.997$, $P < 0.05$).

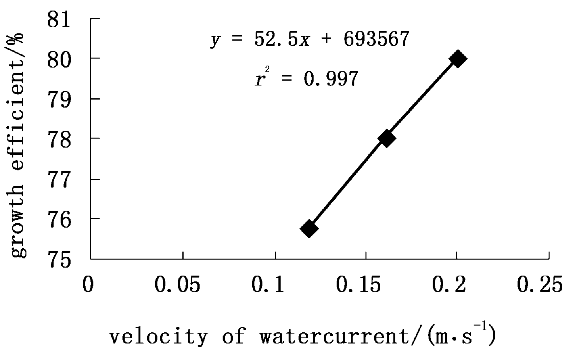

Fig.2 The regression linear between *GE* and velocity of water current

4 Discussion

4.1 Influence of water current on the optimum temperature of juvenile *A. baeri*

From the regression equation, it was found that the juvenile *A. baeri* in V_1 group showed the highest *DGR* of 3.57 % · d^{-1} at 20.5 ℃. Thus, 20.5 ℃ maybe was the optimum temperature for juvenile *A. baeri* cultured in water current velocity of 0.12 m · s^{-1} under the conditions of the indoor intensive fish culture system. Similarly, the optimum temperature for juvenile *A. baeri* in group V_2, V_3, and V_4 were 20.4 ℃, 20.2 ℃ and 20.7 ℃, respectively. The results suggested that the optimum temperature for juvenile *A. baeri* growth was not constant, they changed in the range between 20.2 ℃ and 20.7 ℃. It fluctuates with concrete environmental condition. Besides food, illumination, population density[15] and body weight [16], the interaction of water current and temperature has effect on the growth of juvenile *A. baeri*. Based on these results, it was found that though the optimum temperatures were not the same, they fluctuated between 20.2 ℃ and 20.7 ℃. It suggests that the optimum temperatures are stable for juvenile *A. baeri*. Based on optimum growth temperature of fishes, we can adjust the temperature of tank, save the expenses, and enhance the growth efficiency[17]. Thus, our conclusion here may be helpful to direct the temperature-controlled aquaculture of juvenile *A. baeri*.

4.2 Influence of velocity of water current on the growth of juvenile *A. baeri*

Water current stimulates fish to make corresponding pattern of behavior and mechanism of response. It also acts on the fish body metabolism and then has effects on the growth and development of fish. The effects are positive or negative according to existing reports. Yin considered water current as a negative factor on growth of fishes[18]. In the culture of salmons, people make efforts to avoid exposing fish to the riptide in fish culture systems, otherwise fish are thought to increase the expenditure of energy to keep original position, and result in lower growth rate and higher food cost [17]. But some recent studies showed that growth rate could be improved when salmons were forced to swim with a controlled speed [19]. Houlihan *et al.* [20] proved that the growth rate of rainbow which swim continuously within a fatigue range was two fold as the control group for the biosynthetic rate of protein increasing accordingly. In the present study, *DGR* gradually increased with the velocity of water current increased from 0.12 m · s^{-1} to 0.20 m · s^{-1} when water temperature varied within a range between 16.7 ℃ and 22.5 ℃. The result that *NY* of V_3 group was significantly higher than V_1 and V_2 group suggested that properly increased water current stimulation may be effective on the growth of *A. baeri*. A similar phenomenon was also found in Amur sturgeon *Acipenser sturgeon* [21].

As for the intermittent water current (in half an hour with a velocity of 0.20 m · s^{-1}, then in the next half an hour of intermission), the *NY* and *DGR* of V_4 group were found to be similar to that of V_2 group, but its *FC* lower than that of the other three groups. The oxygen supplying system of our fish culture systems is well designed to ensure a 1.1 kW fan supplying oxygen to 6 – 8 culture tanks when the oxygen-enhancers stop working. Thus, V_4 group can save 30% – 40% power than V_3 group. Thus, V_4 group could be the ideal water current supplying for indoor intensive fish culture systems that attach importance to economic efficiency. Further studies are needed to examine the reasonable water current for sturgeon at different developmental stages, as well as sturgeon of other strains[22]. The present study provides a useful reference to water current and temperature control for the intensive indoor (semi-recirculating) tank culture.

References:

[1] Zhuang P, Li D P, Yan A S. The regulation of crowd press and environmental factors on the growth of Ailing sturgeon[J]. Journal of Fishery Sciences of China, 2003, 10(supple): 55 – 66.

[2] Davidson W A, Goldspink G. The effects of prolonged exercise on the lateral musculature of the rainbow trout[J]. J Exp Biol, 1977, 70(1): 1 – 12.

[3] Houlihan D F, Laurent P. Effects of exercise training on the performance, growth, and protein turnover of rainbow trout (*Salma gairdneri*) [J]. Can J Fish Aquat Sci, 1987, 44: 1614 – 1621.

[4] Li D P, Zhuang P, Yan A S, *et al.* Optimum temperatures for growth and feeding of juvenile Ailing sturgeon *Acipenser schrenckii*[J]. Journal of Fishery Sciences of China, 2005, 12(3): 294 – 299.

[5] Elliott J M. The effects of temperature and ration size on the growth and energetics of salmonids in captivity[J]. Comp Biochem Physiol, 1982, 73 (1): 81 – 91.

[6] Hawkins A D, Soofiani N M, Smith G W. Growth and feeding of juvenile cod, *Gadus morhua* [J]. Cons perm int Explor Mer, 1985, 42(1): 11 – 32.

[7] Hazel J R, Prosser C L. Molecular mechanisms of temperature compensation in poikilothermos [J]. Physiol Rev, 1974, 54: 620 – 677.

[8] Liu S P. Summary on the biology of European sturgeons[J]. Freshwater Fisheries, 1997, 27(3): 26 – 31.

[9] The Yangtze River Fishery Resources Investigation Group of Sichuan Province. Study on biology and artificial propogate of Yangtze River sturgeons [M]. Sichuan Science and Technology Press, 1988:4 – 5.

[10] Lu M X, Huang Z H, Xiao X Z, *et al.* Biology of some sturgeons and paddlefish and prospects for aquaculture [J]. Journal of Dalian Fisheries University, 2000, 15(4): 280 – 286.

[11] Huang N Y, Takeuchi T. Sustainable development of oasis-style ecological and economic system in Yuanyang Lake Area of Jiuquan, Gansu Province of China[J]. The Society of Eco-Engineering, 2005, 17(2): 145 – 150.

[12] Sun D J, Qu Q Z, Ma G J, *et al.* The status of sturgeon culture in China [J]. Journal of Dalian Fisheries University, 2003, 18(3): 216 – 221.

[13] Lin X. Preliminary study on growth characters of juvenile *Acipenser baeri* [J]. Journal of Putian University, 2003: 12(1): 30 – 33.

[14] Chen P Y, Huang Z M. Applied course of SPSS10. 0 stati-stical software[M]. Beijing: People's Arm Medical Press, 2001. 89 – 200.

[15] Christiansen J S, Jobing M. The behavior and the relationship between food intake and growth of juvenile Arctic charr subjected to sustained exercise [J]. Can J Zool, 1990, 68(8): 2185 – 2191.

[16] Qin J D, Fast A W. Effects of temperature size and density on culture performance of snakehead, *Channa striatus* (Bloch), fed formulated feed[J]. Aqua Res, 1998, 19(5): 299 – 303.

[17] Liu J S, Cui Y B, Liu J K. The optimum temperatures for the mandarin fish (*Siniperca chuatsi*) and the northern snakehead (*Channa argus*)[J]. Acta Hydrobiologica Sinica, 2002, 26 (5): 433 – 437.

[18] Yin M C. The fish ecology[M]. Beijing: China Agriculture Press, 1995: 41.

[19] Rice J A. Bioenergetic modeling approaches to evaluation of stress in fishes [C]. American Fisheries Society Symposium, 1990: 8: 80 – 92.

[20] Houlihan D F, Laurent P. Effects of exercise training on the performance, and protein turnover of rainbow trout (*Salmo gairdneri*) [J]. Can J Fish Aquat Sci, 1987, 44(6): 1614 – 1621.

[21] Li D P, Zhuang P, Zhang L Z, *et al.* Domestication of Amur sturgeon(*Acipenser sturgeon*) in the center part of China and its biology VI. effect of water current on the growth of juvenile[J]. Freshwater Fisheries, 2000, 30(3): 42 – 45.

[22] Gao C R, Wang Y G, Lei J L, *et al.* The effects on culture results and water quality of cultured juvenile turbot under the different stocking rates and exchanging rates of water [J]. Marine Fisheries Research, 2004, 25(4): 23 – 27.

流速、温度对西伯利亚鲟幼鱼生长的影响

黄宁宇，　程起群，　高露娇，　么宗利，　夏连军
（中国水产科学研究院东海水产研究所农业部海洋与河口渔业重点开放实验室，上海　200090）

摘要：在 90 d 的饲养实验中，研究了集约化室内储水池养殖条件下，流速和温度对西伯利亚鲟幼鱼生长的影响。按照流速，实验鱼分为 4 组：即流速分别为 V_1 组（0.12 m·s^{-1}），V_2 组（0.16 m·s^{-1}），V_3 组（0.20 m·s^{-1}），和 V_4 组（0.5 h 流速为 0.20 m·s^{-1}，0.5 h 流速为 0 的间隙式水流组）。水温在 13.8 ~24.7 ℃变化。在 16.7 ~22.5 ℃的温度段内，随着流速增大，幼鱼的最终体重、体长、生长效率、净增重、每日生长率及日增重等指标均逐渐增大，饵料系数逐渐降低，其中西伯利亚鲟鱼的生长效率（*GE*）与流速（*V*）之间存在显著正相关性，其关系式为 $GE = 52.5V + 69.567$（$R^2 = 0.997$，$P < 0.05$）。尽管高流速 V_3 组的特殊生长率（*DGR*）是最大的，但 V_3 组在 22.5 ~24.7 ℃之间和 13.8 ~16.7 ℃之间时 *DGR* 是最小的。间隙式水流 V_4 组（0.5 h 流速为 0.20 m·s^{-1}，0.5 h 流速为 0）*DGR* 和净增重（*NY*）不是最高，但其饵料系数（*FC*）和生长效率（*GE*）分别是各组中最低和最高的，而且在高温和低温段 *DGR* 均有比其他组升高的趋势。另外，水流因子与温度交互作用影响西伯利亚鲟幼鱼的生长，本次四组流速组西伯利亚鲟幼鱼的最适生长水温各不相同，在 20.2 ~20.7 ℃之间。结果显示在设施集约化养殖中，V_4 组能够产生较好的效益。

关键词：西伯利亚鲟；生长；集约化养殖；流速；温度
中图分类号：S 917.4；S 931.1　　**文献标识码**：A

收稿日期：2006-07-05
资助项目：上海市科技兴农重点攻关项目（沪农科推字 2004 第 1 –5 –5）
作者简介：黄宁宇（1963 –），男，上海人，副研究员，主要从事水产养殖研究。E-mail：ningyu886@hotmail.com
通讯作者：程起群，Tel：021 –65688139，E-mail：qiquncheng@gmail.com