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Selecting and Fitting Expressive Growth Equations for Different Body Shapes of Fishes

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Abstract

Three relationships: age-length, age-weight, and length-weight in 31 fish species with 14 types of body shapes were fitted and selected through the computer following the principle of least squares sum. Sixty-three out of the 86 cases were fit to be expressed using the quadratic equation, $Y=a + bx + cx^2$, which accounted for 73.256% of the total number of cases. Checking computations and comparisons were made with the growth of silver carp *Hypophthalmichthys molitrix* that also served as an example.

Introduction

The study on age and growth is a basic content of fish biology. To be able to estimate fish resource dynamics and program fishery management in certain waters, it is equally important to find out the relationship between age and growth and express it in mathematical ways. To date, many of the scientific workers who have contributed a lot in this aspect (Qingjiang 1975; Chuanfuh et al. 1978; Shiqin and Yachu 1980; Zhonglin et al. 1981; Qiyong et al. 1981; Xuezu and Mingcheng 1983; Yuhao and Xiaopin 1984; Bangxi 1984; Bangxi et al 1986; Zhaohe 1987; Shushun et al. 1989; Sifa et al. 1990; Makang et al. 1990; Yongle et al. 1990; Guoying 1990; Dong and Jianlong 1990; Zhiling et al. 1990; Qigui and Xuefu 1992; Mingsheng 1993) employed the von Bertalanffy (1938, 1957) growth equation to express fish growth. Fabens (1965) reported the properties and fitting of von Bertalanffy growth curve. Allen (1966) performed a fitting study on the von Bertalanffy curve using the least squares sum method. Although a number of scholars proposed that in fitting the growth of fishes, it is better to use the quadratic equation than the von Bertalanffy and logistic (Pearl and Reed 1920) equations, only a few utilized the quadratic equation due to its complicated computations (Kefei 1987; Changcheng 1990). Furthermore, some researchers believed that the characteristics of fish growth varied with fish species and their body shapes. Even if fishes were of the same shape or of the same species in different environments, their growth characteristics also differed a lot accordingly. Therefore, the appropriate growth expressions were not identical either (Yuanyu and Chuanlin 1981; Yuanyu and Jingrong 1983). In view of the facts presented, the study on fitting and selecting growth equations for different body shapes of fishes was made not only to meet the need of transferring fish biology data from qualitative description to quantitative analysis, but also to provide basis for fitting and selecting the best equation to be used in expressing the relationship between age and growth in fishes.

Materials and Methods

The main cultured fishes with different body shapes in China's freshwaters were chosen for the fitting study. Similarly shaped fishes were grouped into one shape pattern. Thirty-one species of commonly found fishes were grouped into 14 shape patterns in the light of geometric differences in the externals (Table 1). The specimen number of each fish is listed in table 1.

Eight equations most commonly used in biology to describe the growth of fishes were synthetically programmed in the computer (Program omitted here). Judged by the least squares sum, three groups of data, i.e. the data of age (*Y)* and body length (*L*), age and body weight (*W*), and body length and body weight of the 31 fishes with 14 body shapes were entered into the computer and formulated. According to the initial measured data, the units of body length of all the 31 fish species were in expressed centimeters. The units of body weight of common carp, black carp, yellow cheek carp and seasonal shad were in kilograms, while the other species were in grams. As to age, month was employed for icefish, and year for all the others. The eight equations used in the studies are listed in table 2.

Results

Three relationships (age-length, age-weight, and length-weight) describing the growth of fishes were fitted using the eight equations listed in table 2. Out of the 86 cases, 63 were well expressed using the quadratic equation (Table 1). Among these, age-length correlation accounted for 16 cases, age-body weight for 24 cases and length-weight for 23 cases, which constituted 73.256% of the total number of cases. Eight cases were suitable for logistic equation, among which, two cases were for age-length correlation, three were for age-weight and three were for length-weight, with a proportion of 9.302% of the total cases. Three cases with a proportion of 3.488% were fitted using the hyperbolic equation, while six cases were fitted using the power equation. Among these, age-length and length-weight correlations each accounted for the three cases respectively, with a proportion of 6.977% of the total cases. Six cases of age-length could be expressed using the logarithmic equation with a proportion of 6.977%. Linear equation, exponential equation and inverse equation were removed because they were not selected in the computations.

Discussion

In a biological study, logistic growth equation is the classic equation used to express fish growth. The shape of the equation is an S-curve. Theoretically it reflects various growth characteristics during different periods in the overall life cycle of fishes. Generally, the curve is divided into five growth stages: initial stage, accelerating stage, inflecting stage, decelerating stage and stagnating stage. These five stages may be expressed using related equations respectively. There is a growth inflection point during the inflecting stage. The asymptotic value C of the curve may be used as the maximum carrying capacity of the environment.

With reference to the stages Yanling et al (1981) gave a rather detailed description while studying the relationship between primary production and fish yield in waters. However, when the logistic equation was used to deal with the data, obtaining the parameters requires long life cycles of fishes and integrated age groups with enough samples, especially with a certain number of samples of the youngest and oldest age groups. Otherwise it is difficult to calculate the parameters of equation. This may cause errors between the calculated results and the actually measured values.

The von Bertalanffy growth equation was derived on the basis of fish energy metabolism, assuming that the body weight of fish is proportional to the body length's volume. The samples' conditions in applying this equation are the same as the logistic equation, and the characteristics of growth are not as objective as the latter. This can be seen from the difference in the figures of the first and last growth stages. Since the shape of the von Bertalanffy curve is an asymmetric "S" curve, it often results to some errors between the calculated and the actually measured values of samples from the youngest and the oldest age groups. The generation of these errors is known as the Rosa Lee Phenomenon (Richer 1975). Pitcher (1982) also gave a detailed discussion on the application of the von Bertalanffy growth equation.

It is worth demonstrating that both the quadratic equation and the von Bertalanffy growth equation are the same in reflecting growth characteristics and both required sample compositions. However, the former hardly shows the Rosa Lee phenomenon. Based on the actually measured data of 169 silver carps, checking computations and comparisons were performed between the two equations (Table 3). The result showed that the formulated values of quadratic equations were closer to the measured values than that of the von Bertalanffy equation.

Table 1. Selecting and fitting on optimum expressive equations of growth for different body shapes of fishes.

Body shape	Fish species	Specimen number	Relation-ship	Selected optimum expression								Express equation	Value of least residue quadratic sum
				1	2	3	4	5	6	7	8		
Silver carp shaped	Silver carp	169	*L-Y*								•	$L=36.2199+3.4771Y+0.8571Y^2$	7.3982
			W-Y								•	$W=2580.8730-1398.2460Y+536.4659Y^2$	1.5534×10^5
			W-L								•	$W=6.1998-0.2931L+4.4053\times10^{-3}L^2$	0.2020
	Bighead carp	30	*L-Y*								•	$L=28.2856+6.0083Y+0.7654Y^2$	35.3452
			W-Y							•		$W=19.1495\cdot(1+190.1369e^{-0.06880L})^{-1}$	2.6085
			W-L							•			1.1866
Grass carp shaped	Black carp	38	*L-Y*		•							$L=7.0659+57.2512\lg Y$	29.8305
			W-Y								•	$W=-5.0799+3.1806Y+0.1392Y^2$	1.3531
			W-L				•					$W=3.2013\times10^{-5}L^{2.8330}$	0.7603
	Grass carp	74	*L-Y*								•	$L=25.3499+11.2053Y-0.2089Y^2$	55.6932
			W-Y						•			$W=Y\cdot(1.1614-0.1105Y)^{-1}$	1.8813
			W-L								•	$W=3.1247-0.1799L+3.3017\times10^{-3}L^2$	0.2870
	Babel chub	166	*L-Y*		•							$L=16.0344+13.2161\lg Y$	*2.7365*
			W-Y								•	$W=-9.0941\times10^{-2}+0.1527Y+6.5676\times10^{-3}Y^2$	8.1011×10^{-2}
			W-L								•	$W=0.9819-9.3313\times10^{-2}L+2.4302\times10^{-3}L^2$	0.512
	Yellow-cheek carp	229	*L-Y*						•			$L=Y\cdot(1.9112\times10^{-2}+4.3503\times10^{-3}Y)^{-1}$	11.6876
			W-Y								•	$W=-5.0297+5.0185Y+0.2885Y^2$	8.9211
			W-L				•					$W=8.4953\times10^{-6}L^{3.1214}$	7.0186×10^{-4}
	Striped mullet	167	*L-Y*								•	$L=23.0101+10.1478Y-0.6221Y^2$	0.9498
			W-Y								•	$W=-0.1973+0.7016Y+1.6345\times10^{-3}Y^2$	5.6279×10^{-2}
			W-L								•	$W=1.5146-0.1082L+2.4222\times10^{-3}L^2$	2.0434×10^{-2}
Common carp shaped	Common carp	55	*L-Y*		•							$L=22.4040+22.5369\lg Y$	11.5180
			W-Y								•	$W=-0.1170+0.9159Y-1.5358\times10^{-2}Y^2$	0.2323
			W-L								•	$W=2.7028-0.1467L-2.9352\times10^{-3}L^2$	9.1345×10^{-2}
	Crusian carp	48	*L-Y*						•			$L=Y\cdot(0.1695+2.0201\times10^{-2}Y)^{-1}$	6.7322
			W-Y								•	$W=-32.1642+32.0625Y+2.8958Y^2$	2.9691×10^3
			W-L								•	$W=9.0079-6.5698L+0.9376L^2$	6.3169×10^2
	Nile tilapia	248	*L-Y*								•	$L=16.6663-0.2005Y+0.6623Y^2$	2.9044×10^{-2}
			W-Y								•	$W=197.7035-21.1947Y+21.6457Y^2$	14.3222
			W-L										
	Mud carp	214	*L-Y*							•		$L=65.6513\cdot(1+4.7160e^{-0.3067Y})^{-1}$	0.9019
			W-Y								•	$W=62.8043-96.2281Y+48.2631Y^2$	3.8912×10^3
			W-L								•	$W=446.6630-60.8058L+2.1789L^2$	1.9139×10^3
Mandarin fish shaped	Mandarin fish	73	*L-Y*				•					$L=14.2122Y^{0.5610}$	*0.1965*
			W-Y								•	$W=2.3121\times10^{-2}+9.7658\times10^{-3}Y+4.0807\times10^{-2}Y^2$	5.2311×10^{-4}
			W-L								•	$W=0.4812-5.9476\times10^{-2}L+2.1821\times10^{-3}L^2$	3.2298×10^{-3}
	Japanese sea perch	49	*L-Y*				•					$L=33.4503Y^{0.5514}$	4.3383
			W-Y								•	$W=1.9829-1.6495Y+0.5588Y^2$	3.6238
			W-L								•	$W=8.8099-0.3950L+4.6898\times10^{-3}L^2$	5.1593
Black bream shaped	Black bream	632	*L-Y*							•		$L=56.3571\cdot(1+5.5896e^{-0.6541Y})^{-1}$	18.0708
			W-Y							•		$W=3632.8880\cdot(1+140.0825e^{-1.0546Y})^{-1}$	1.7596×10^5
			W-L								•	$W=1103.4570-107.0678L+2.7732L^2$	2.0105×10^5
	Seasonal shad	348	*L-Y*								•	$L=34.9386+3.3571Y+3.3934\times10^{-2}Y^2$	11.6412
			W-Y								•	$W=-0.20+0.5975Y-7.1446\times10^{-4}Y^2$	0.1536
			W-L								•	$W=-7.6867+0.2422L-8.2209\times10^{-4}L^2$	0.1818
Puffer shaped	Drab filefish	575	*L-Y*								•	$L=74.3702+49.8422Y-3.6089Y^2$	36.4182
			W-Y								•	$W=-8.8604+46.0567Y+0.4821Y^2$	3.2718×10^2
			W-L								•	$W=204.7198-2.9443L+1.3320\times10^{-2}L^2$	32.7406
Redfin culter shaped	Mongolian culter	201	*L-Y*		•							$L=13.6235+13.8064\lg Y$	6.5002
			W-Y								•	$W=2.3492\times10^{-2}+5.3163\times10^{-2}Y+1.0699\times10^{-2}Y^2$	4.1832×10^{-3}
			W-L								•	$W=0.4423-0.0445L+1.3734\times10^{-3}L^2$	8.9981×10^{-3}
	Estuarine tapertail anchovy	765	*L-Y*								•	$L=17.8799+1.8671Y+0.4071Y^2$	27.9302
			W-Y								•	$W=-21.80+28.5571Y+2.3571Y^2$	3.9841×10^3
			W-L								•	$W=178.0174-17.4588L+0.4847L^2$	4.3880×10^2
	Sharpbelly	67	*L-Y*								•	$L=2.3600+4.7071Y-0.2928Y^2$	4.6286×10^{-2}
			W-Y							•		$W=89.3239\cdot(1+28.5159e^{-1.009Y})^{-1}$	70.7559
			W-L								•	$W=20.0797-4.5075L+0.4098L^2$	50.2535
Small-scale yellow-fin shaped	Small-scale yellowfin	197	*L-Y*								•	$L=13.1600+7.9328Y-0.6357Y^2$	1.2277×10^{-2}
			W-Y								•	$W=-0.0694+0.2301Y-9.0177\times10^{-3}Y^2$	0.3005
			W-L								•	$W=0.2081-2.8575\times10^{-2}L+1.2640\times10^{-3}L^2$	1.7777×10^{-2}
	Spotted steed	484	*L-Y*		•							$L=3.4554+12.9372\lg Y$	26.6938
			W-Y								•	$W=-2.8111+22.3277Y+3.1730Y^2$	82.1942
			W-L								•	$W=26.7517-10.4916L+0.7485L^2$	82.6107
Snake-head shaped	Snakehead	52	*L-Y*								•	$L=21.8705+3.8349Y+1.1750Y^2$	4.5001×10^{-3}
			W-Y								•	$W=590.8503-454.40Y+228.40Y^2$	1.4045×10^2
			W-L								•	$W=734.5490-55.5545L+1.5337L^2$	3.0486×10^3

continued

Table 1 continued

Body shape	Fish species	Specimen number	Relation-ship	Selected optimum expression 1	2	3	4	5	6	7	8	Express equation	Value of least residue quadratic sum
catfish shaped	Long-snout catfish	303	*L-Y*								•	L=9.1507+12.8380Y+0.4571Y^2	11.7825
			W-Y								•	W=-0.5055+0.4731Y+4.1192×$10^{-2}Y^2$	0.1222
			W-L								•	W=0.0919-2.3760×$10^{-2}L$+1.1155×$10^{-3}L^2$	0.1947
	Chinese sheatfish	174	*L-Y*			•						L=40.6131$Y^{0.4867}$	4.7164
			W-Y								•	W=-0.3185+0.8761Y+0.1036Y^2	0.2448
			W-L			•						W=8.9279×$10^{-2}L^{3.0161}$	0.1655
	Burbot	219	*L-Y*		•							L=29.8352+11.5953lg$Y$	1.2028×10^3
			W-Y								•	W=114.1006-61.0325Y+49.1679Y^2	1.4121×10^5
			W-L								•	W=245.5558-28.2608L+0.9364L^2	2.2108×10^2
Rhinogobio shaped	*Rhinogobio ventralis*	100	*L-Y*										
			W-Y										
			W-L								•	W=20.6005-0.5178L+3.7769×$10^{-3}L^2$	1.4717×10^{-7}
	Pond smelt	200	*L-Y*								•	L=3.3200+4.8613Y-0.1785Y^2	0.4845
			W-Y								•	W=106.4197-77.2066Y+20.7971Y^2	1.8539×10^4
			W-L							•		W=380.5085·(1+108.9006e$^{-0.2492L}$)$^{-1}$	25.2623
Rice-field Eel shaped	Ricefield	210	*L-Y*								•	L=15.7469+9.7381Y-0.2669Y^2	10.8455
			W-Y								•	W=49.1396-43.8254Y+15.8713Y^2	1.5047×10^2
			W-L							•		W=1108.1130·(1+646.8310$e^{-8.7866\times10\text{-}2L}$)$^{-1}$	2.7705×10^3
	Japanese eel	31	*L-Y*										
			W-Y										
			W-L								•	W=334.7548-24.5647L+0.4661L^2	2.1686×10^3
Icefish shaped	Large ice-fish	44	*L-Y*								•	L=-22.3155+29.1017Y-1.4445Y^2	1.4555×10^2
			W-Y										
			W-L										
Loach shaped	Loach	27	*L-Y*								•	L=4.4500+3.9732Y-0.1839Y^2	4.1785×10^{-2}
			W-Y								•	W=-6.6100+10.5475Y+0.5589Y^2	20.9623
			W-L								•	W=-0.8389-1.0217L+0.2106L^2	30.2228

Table 2. List of equations used in the study.

Linear equation	$Y = a + bx$	1
Logarithmic equation	$Y = a + b\lg x$	2
Exponential equation	$Y = ae^{bx}$	3
Power equation	$Y = ax^b$	4
Inverse equation	$Y = 1\cdot(a + bx)^{-1}$	5
Hyperbolic equation	$Y = x\cdot(a + bx)^{-1}$	6
Logistic equation	$Y = c\cdot(1 + ae^{-bx})^{-1}$	7
Quadratic equation	$Y = a + bx + cx^2$	8

Table 3. Comparison of checking computation results by two equations for silver carp.

Age groups	Specimen no.	Measured body length (cm)		Measured body weight (g)		Bertalanffy equation		Quadratic equation	
		Range	Mean±SD	Range	Mean±SD	Body length[1]	Body weight[2]	Body length[3]	Body weight[4]
1^+	105	28.5-50.2	39.7±5.0	500-2800	1360.9±486.0	23.0788	254.9033	40.5541	1719.0929
2^+	43	36.0-59.0	48.3±6.2	900-4450	2589.4±137.5	40.5972	1387.4632	46.6025	1930.2446
3^+	15	43.0-64.8	54.4±5.6	2500-6250	3386.0±949.6	54.3693	3332.6976	54.3651	3214.3281
4^+	3	50.0-70.0	61.2±10.1	2500-6250	4683.3±1949.6	65.1964	5746.5162	63.8419	5571.3434
5^+	3	74.2-79.0	75.9±2.7	7500-11500	9416.7±2005.2	73.7082	8303.8693	75.0329	9001.2905

[1] $L=105.0[1-e^{-0.2046(t+0.0316)}]$

[2] $W=24005.0[1-e^{-0.2046(t+0.0316)}]^3$

[3] $L=36.2199+3.4771Y+0.8571Y^2$

[4] $W=2580.873-1398.246Y+536.4659Y^2$

It is further verified while analyzing the growth characteristics of the fishes with short life cycles and insufficient oldest and/or youngest age groups, that the application of quadratic equation is preferable. The results were consistent with the views of Kefei (1987) and Changchen (1990). In the calculations of the 86 cases, 63 were well expressed using the quadratic equation and ranked first among the eight equations. Among the 29 cases of formulations of the relationship between body length and body weight, 23 were expressed using the quadratic equation, while power equation and logistic equation were each fitted in three cases but comparisons between the theoretical and actual values measured showed that power equation was the best.

The equation used in selecting the expressions of age and growth relationship based on the fishes' body shapes did not show the obvious selectivity in this paper. Only the values of parameters differred from each other when the same equation was utilized.

Conclusion

Two growth relationships, age-body length relationship and age-body weight relationship were suitably expressed using the quadratic equation, while length-weight relationship was appropriately described using the power function equation.

The various shapes of fishes did not show obvious selectivity to the eight equations used in this paper. Three equations, linear equation, exponential equation and inverse equation were not selected in the fitting calculations and were therefore removed.

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