The growth of rudd *Scardinius erythrophthalmus* (Cyprinidae) in the watershed of the River Sarysu

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Abstract. Within Central Kazakhstan, rudd (*Scardinius erythrophthalmus*) inhabit a variety of types of water bodies belonging to the Ponto-Aral-Caspian ichthyogeographic province. Three samples from this water system studied in different years did not differ significantly in terms of the back-calculation of growth in body length. The studies also showed that there was also no sexual and generational variability in growth rates. The sufficiently high level of correlation of the calculated body length in adjacent generations was found, showing the constancy of the factors influencing it and the stability of the habitat as a whole. The asymptotic body length of the von Bertalanffy equation $L\infty$ and the Pauly-Munro growth-performance index were clearly more positive for samples from the River Sarysu and the Bidaikskoe reservoir, as well as for the condition factor and the calculated weight growth. The main factor influencing the growth rate of rudd in the watershed of the Sarysu is likely to be the dynamics of the hydrological regime, which causes the appearance of a negative temperature regime in shallow waters. Comparing the results obtained across the three studies with previously published data, it is clear that the growth rates of this species in this watershed can be seen as average.
Key Words: back calculation, correlation, rudd, variability, von Bertalanffy equation.

Introduction. The fish fauna of the waters of Central Kazakhstan are largely populated by species of Siberian origin (Krainyuk 2011). However, the general Siberian appearance of fish communities from the south is interspersed by mountainous Asian and Ponto-Aral-Caspian species. Mountainous Asia here refers to Lake Balkhash and its system, while Ponto-Aral-Caspian refers to the watershed of the River Sarysu.

The fish fauna of the Sarysu includes many species that live in milder hydroclimatic conditions. Here lies the northern border of the distribution of the golden spiny loach *Sabanejewia aurata*, the catfish *Silurus glanis*, the carp *Cyprinus carpio*, the asp *Leuciscus aspius*, and the rudd *Scardinius erythrophthalmus*. According to recent studies (Kozhara et al 2020), the southeastern (Aral) populations of rudd deserve to be identified as a different species.

The brightly colored fins of the roach *Rutilus rutilus* means that it is often confused with the rudd. The Russian and Kazakh names for the rudd make a rather ironic joke here, as they translate as "red fins". However, the rudd differs from the roach by not possessing brightly colored fins. Differentiating between the genera *Rutilus* and *Scardinius* is based on the different rows of pharyngeal teeth (Berg 1949; Mitrofanov et al 1987).

It is worth noting again that the rudd does not live in waters north of the watershed of the River Sarysu (Berg 1949; Mitrofanov et al 1987; Krainyuk 2011). This species may well survive during the growing season in any of the bodies of water in Central Kazakhstan but its naturalization here is impossible or involves great efforts in connection with the species' environmental preferences by our opinion.

This article describes the results of studying the growth of rudd in the system of the River Sarysu. The back-calculated linear and weight sizes, annual growth rates, and a number of other growth functions were evaluated. Intergroup and intragroup variability was assessed.

Most of the data on the back-calculation of the growth (also in general on growth) of rudd, like most non-commercial fish species, has already been published in extremely old scientific publications. New information is extremely rare. This applies not only to the former Soviet Union but internationally. Therefore, any correct data regarding growth, as well as other aspects of the biology of these species, will be relevant.

Material and Method. The material was collected through fieldwork between 2011 and 2020 and processed *ex tempera*. Gill nets were used to catch the fish. Standard measurements and calculations were made (standard length, body weight, carcass weight, condition factors, etc.) (Pravdin 1966). To determine the age and carry out the back-calculation of growth, scales were used (Chugunova 1959). Annuli rings were determined using an MBS-10M binocular microscope (JSC LZOS, JSC Shvabe Holding, Rostec State Corporation, Russia), measurements were carried out at 8x magnification using an eyepiece with a scale. The following numbers and locations of specimens were analyzed: 11 fish from the Bidaikskoe reservoir; 27 from the River Zhaman-Sarysu (near the village of Tselinnoye); and 47 from the River Sarysu (180 km south of the town of Zhezkazgan). The locations of the sampling points are shown in Figure 1.

Figure 1. Sampling points.

Growth was calculated using the Dahl-Lea simple ratio method (Francis 1990). According to some studies (Dgebuadze 2001), the use of direct proportions gives a more accurate result. Annual growth was taken as the difference between annual values (Il'mast 2005). To assess the relationship of growth in adjacent years of life, the Pearson correlation coefficient (Plokhinsky 1970) was used. The calculation of this coefficient was made using the IBM SPSS v. 22 program (Buhl & Zofel 2005).

The constants of the von Bertalanffy equation (hereinafter VBGE) were calculated using the variables α and β of the Ford-Walford equation. The following were determined: asymptotic length $L\infty$, growth constant (catabolic coefficient) k and "initial age" t_0

(Milovanov 2019). Based on these indicators, the Poly-Munroe index of growth performance was calculated (Pauly & Munro 1984).

The use of the Vaughan-Burton method, or the so-called "last mark" (Vaughan & Burton 1994), in the preparation of the initial data for calculating the VBGE equation was considered inappropriate, due to the absence of the Rose Lee phenomenon. Weight growth was calculated on the basis of length-weight relationship (LWR) according to the Hilborne-Waters method (Hilborn & Walters 1992). The constants k and t_0 are determined from the Bertalanffy equation and the coefficients a and b from the equation of LWR (Froese 2006). Carcass weight was used here as it is less susceptible to stochastic changes.

The data obtained were statistically processed (Plokhinsky 1970) using the MS Excel 2003 program (Korosov & Gorbach 2007). Analysis of variance (ANOVA) and correlation analyzes were performed using the IBM SPSS v. 22 (Buhl & Zofel 2005). Differences were recognized as significant for analysis of variance at a confidence level of $\alpha \leq 0.05$; and for correlation analysis at $\alpha \leq 0.01$.

In addition to the standard ones, the following abbreviations and notations are used in this work: res. - reservoir, riv. - river, F - value of Fisher's criterion, σ - standard deviation, G – annual growth, QC – Clark's condition factor.

Results. Table 1 shows the materials of the original research and the data relating to the back-calculation of the growth of the rudd. As already noted, most of the previous studies were conducted over a period of 70 years (Nickolsky 1940; Turdakov & Piskarev 1955; Serov 1956, 1959; Seleznev 1963; Zhukov 1965; Movchan & Smirnov 1981; Mitrofanov et al 1987; Boznak 2008). The samples originating from the watershed of the River Sarysu between 2011 and 2020 hardly differ from one another as far as ANOVA is concerned. The only significant difference is observed at the age of five years at very low values for the River Zhaman-Sarysu ($F = 4.52$; $\alpha = 0.017$).

In general, the linear growth of rudd, like most other freshwater cyprinids from waters in temperate latitudes, depends on the state of the food supply, the presence of trophic competitors and predators (Yazici et al 2015), as well as on a complex of abiotic factors (Tarkan et al 2010). All these usually constitute a single complex that affects the processes of growth and ontogenesis.

Table 1

Back-calculation of growth (cm) of rudd from the watershed of the River Sarysu and other water bodies

Water	*Years of lifespan*									*Year of collecting or reference*
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	
				Watershed of River Sarysu						
Reservoir Bidaikskoe	5.4	8.8	12.3	15.0	17.5	19.8	-	-	-	2015
River Zhaman-Sarysu	5.3	9.0	11.8	14.5	16.4	18.9	-	-	-	2011-2012
River Sarysu	5.2	8.6	12.0	15.3	18.0	20.0	-	-	-	2018-2020
Reservoir Dzezkazganskoe	3.2	7.7	10.8	13.0	-	-	-	-	-	Goryunova (1956)
River Sarysu	4.9	8.4	11.8	14.5	17.0	19.1	-	-	-	Yerestchenko (1956)
Lakes Tilikol	5.7	8.5	12.9	-	-	-	-	-	-	Bening & Nickolsky (1933)
Lakes Tilikol, 1964	7.3	12.0	16.5	19.4	-	-	-	-	-	Mitrofanov et al (1987)
Lakes Tilikol, 1967	4.4	8.6	13.0	-	-	-	-	-	-	Mitrofanov et al (1987)

Watershed of River Chu										
Pound Communa	5.0	8.7	13.0	-	-	-	-	-	-	Turdakov (1963)
River Chu	6.1	10.2	11.7	12.7	16.5	-	-	-	-	Turdakov & Piskarev (1955)
Watershed of Aral Sea										
Sea of Aral	5.9	11.5	16.3	19.5	22.4	-	-	-	-	Nickolsky (1940)
Lake Sudochie	6.3	10.2	14.0	17.3	20.1	23.0	-	-	-	Nickolsky (1940)
Reservoir Farkhadskoe	7.9	11.9	14.8	17.4	20.2	-	-	-	-	Movchan & Smirnov (1981)
Lake Karakol	6.7	9.5	11.7	13.7	-	-	-	-	-	Mitrofanov et al (1987)
River Aksay-Kuvandaria	3.9	8.1	12.3	15.6	18.8	-	-	-	-	Mitrofanov et al (1987)
Lakes Kamushlybash	5.1	9.3	13.1	16.6	19.9	22.2	-	-	-	Mitrofanov et al (1987)
Reservoir Chardariinskoe	5.1	9.0	11.9	14.8	17.4	19.7	-	-	-	Mitrofanov et al (1987)
Lake Karateren	5.4	9.4	12.6	15.9	17.7	-	-	-	-	Movchan & Smirnov (1981)
Lake Dautkul	5.5	10.1	13.7	17.1	20.4	-	-	-	-	Movchan & Smirnov (1981)
Watershed of River Ural										
River Ural	3.9	7.7	10.5	12.6	-	-	-	-	-	Mitrofanov et al (1987)
Lake in river Ural floodplain	4.2	8.5	12.3	16.0	18.8	-	-	-	-	Mitrofanov et al (1987)
Reservoir Yembulatovka	4.6	6.9	9.6	11.7	15.2	-	-	-	-	Mitrofanov et al (1987)
Lake Chelkar	7.3	9.5	13.4	16.4	20.1	22.3	-	-	-	Serov (1956)
Lakes Kamysh-Samarskie	6.2	9.6	12.6	15.5	19.2	20.9	-	-	-	Serov (1959)
River Uyil	5.9	10.3	13.9	17.4	20.9	24.9	-	-	-	Mitrofanov et al (1987)
Watershed of River Volga										
River Volga riv. delta	4.9	9.3	15.8	21.7	26.2	28.8	30.8	32.3	33.3	Movchan & Smirnov (1981)
River Oka floodplain lakes	3.9	7.7	11.2	15.8	19.0	21.8	24.0	-	-	Seleznev (1963)
Watershed of River Western Dvina										
River Western Dvina	3.2	6.8	9.5	12.3	15.0	17.4	18.6	19.7	-	Zhukov (1965)
Watershed of River Dnepr										
Watershed of River Dnepr	3.2	6.6	9.6	12.4	14.6	16.3	-	-	-	Zhukov (1965)
River Dnepr	3.2	6.3	9.0	11.0	12.8	-	-	-	-	Zhukov (1965)
Watershed of River Mius										
Pound Severinovsky	4.8	7.4	10.1	12.4	13.9	15.5	17.5	-	-	Movchan & Smirnov (1981)
Watershed of River Northern Dvina										
Lake Stchuchie	3.4	6.1	8.1	10.3	-	-	-	-	-	Boznak (2008)
River Luza riv.	4.2	6.7	8.2	10.9	-	-	-	-	-	Boznak (2008)

Sexual growth variability in Sarysu rudd is not seen (Table 2), with the exception of a single water body in a five-year old fish in a sample from the River Sarysu (F = 4.32; ɑ = 0.045).

Table 2

Variability in growth (cm) by sex for rudd

Water body	*Sex*	*Years of lifespan*					
		1	*2*	*3*	*4*	*5*	*6*
River Sarysu	female	5.2	8.6	12.1	15.0	18.1*	20.0
	male	5.2	8.0	11.3	14.7	17.2*	-
River Zhaman-Sarysu	female	5.2	9.1	11.9	14.4	16.4	18.9
	male	5.3	8.8	11.5	15.2	-	-
Reservoir Bidaikskoe	female	5.5	8.8	12.3	15.1	17.5	19.8
	male	4.4	8.8	12.3	14.8	-	-

* = significant values at p ≤ 0.05.

Generational growth variability is also weak (Table 3). There was only one case (namely River Sarysu) of significant difference in analysis of variance in individuals from the River Sarysu, at the age of three (F = 3.29; ɑ = 0.0014).

Table 3

Variability in generational growth (cm) of rudd

Year of birth	*Years of lifespan*					
	1	*2*	*3*	*4*	*5*	*6*
			River Sarysu			
2012	5.9	9.7	13.0*	15.8	18.0	20.0
2013	5.2	8.8	12.4*	15.6	18.0	-
2014	5.4	8.8	12.3*	15.2	-	-
2015	5.3	8.2	11.5*	14.7	17.9	-
2016	4.3	7.5	11.3*	15.1	-	-
2017	4.6	9.6	13.6*	-	-	-
			River Zhaman-Sarysu			
2005	5.9	9.3	12.2	14.8	16.6	18.9
2006	4.7	8.7	11.0	13.5	16.2	-
2007	5.0	8.9	12.3	14.6	-	-
2008	4.8	8.7	11.5	-	-	-
2009	5.4	8.6	11.4	-	-	-
2010	5.6	9.3	-	-	-	-
			Reservoir Bidaikskoe			
2009	5.5	8.0	12.1	14.6	17.3	19.8
2010	5.6	9.2	12.6	15.3	17.6	-
2011	4.6	8.0	11.5	14.7	-	-
2012	5.5	9.1	12.4	-	-	-

* = significant values at p ≤ 0.05.

The succession of growth rates for the rudd during its life is high (Table 4). The following year's performance for rudd from both rivers is strongly dependent on the previously achieved values. This indicates the constancy of the nature of the habitat impact, regardless the sign of this stability. Accordingly, the factors that have the main influence on growth remain constant. In the Bidaikskoe reservoir, this correlation is weak and is only seen in the time interval following the age of mass maturity and first spawning (Mitrofanov et al 1987). This shows less canalization of growth depending on the habitat conditions in the reservoir as compared to rivers. In the reservoir, in our opinion, there are the conditions for intensification of growth after a period of lag.

Table 4

Correlation of calculated body length for adjacent ages

Water body	*Pearson correlation coefficient*			
	1/2	*2/3*	*3/4*	*4/5*
River Sarysu	0.715*	0.646*	0.714*	0.581*
River Zhaman-Sarysu	0.740*	0.438	0.955*	1.000*
Reservoir Bidaikskoe	0.526	0.320	0.861*	0.543

* = significant values at $p \leq 0.01$.

Table 5 shows the variability in body length at one year of age depending on the year of lifespan. This analysis was performed to identify the Rose Lee phenomenon. There were no significant differences between age classes, as well as the direction of variability. This allows us to speak about the absence of this phenomenon in the samples of rudd studied.

Table 5

Calculated body length (cm.) at the age of one year in individuals with different ages

Water body	*Age, full years*				
	2	*3*	*4*	*5*	*6*
River Sarysu	-	5.7	4.9	5.2	5.9
River Zhaman-Sarysu	5.6	5.1	5.0	4.7	5.9
Reservoir Bidaikskoe	-	5.5	4.6	5.6	5.5

Annual growth in the groups of rudd which were studied has a different character and rate (Table 6). In fish from the River Sarysu and the Bidaikskoe reservoir, the growth curve is quite different from the population in the River Zhaman-Sarysu (Figure 2).

Table 6

The annual growth (G, cm) and standard deviation of annual growth (σ_G)

Water body	*Index*	*Years of lifespan*				
		2	*3*	*4*	*5*	*6*
River Sarysu	G	3.3	3.5	3.3	2.7	2.1
	σ_G	0.76	0.89	0.77	0.84	0.49
River Zhaman-Sarysu	G	3.7	3.0	2.3	2.3	2.3
	σ_G	0.61	0.95	0.29	0.64	-
Reservoir Bidaikskoe	G	3.4	3.5	2.8	2.4	2.5
	σ_G	0.96	1.08	0.75	0.62	-

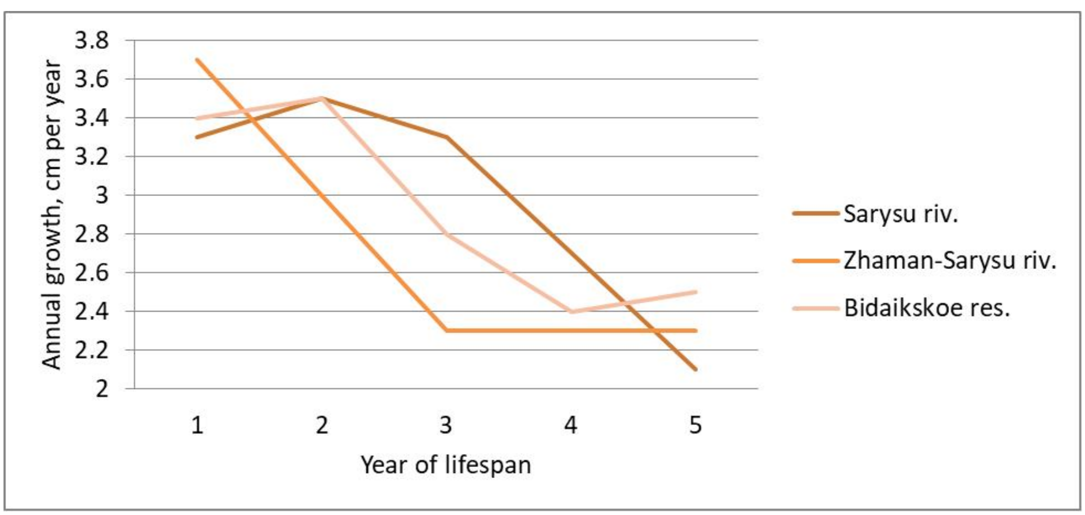

Figure 2. Distribution of annual growth for rudd from the watershed of the River Sarysu.

The high growth rates of the rudd from the Zhaman-Sarysu decrease at a faster rate than in the other two samples. A similar growth pattern is subsequently reflected in the indicators of the Bertalanffy equation and the Poly-Munro index.

The calculated indicators for the von Bertalanffy equation and the growth efficiency index show theoretically better indicators for individuals from the River Sarysu and the Bidaikskoe reservoir (Table 7).

Table 7

Constants of the von Bertalanffy equation and the Poly-Munroe growth efficiency index (Φ')

Water body	L_∞	*k*	t_o	*Φ'*
River Sarysu	40.6	0.109	-0.28	2.25
River Zhaman-Sarysu	34.1	0.128	-0.31	2.17
Reservoir Bidaikskoe	39.5	0.110	-0.34	2.23

The calculation of weight growth (Table 8) shows excessively high values of w∞. However, these are just theoretical calculations and individuals in these populations cannot reach such sizes.

Table 8

Calculated carcass weight growth (gr) and Clark’s condition factor

Water body	w_∞	Q_C	*LWR*		*Calculated carcass weight*					
			a	*b*	*1*	*2*	*3*	*4*	*5*	*6*
River Sarysu	1538	2.21	0.012	3.166	3	15	39	76	124	181
River Zhaman-Sarysu	1071	1.99	0.010	3.215	2	11	31	61	101	149
Reservoir Bidaikskoe	1596	2.22	0.013	3.198	3	14	37	72	119	176

The determination of weight for years of life by this method shows a fairly plausible result, in contrast to the calculated asymptotic weight w∞. Here, again, the populations from River Sarysu and the Bidaikskoe reservoir show the greatest rate of weight growth. They also have better meaning of condition factor.

Discussion. In the watershed of the River Sarysu, the main trophic competitor of rudd, as a "pronounced" phytophage (Mitrofanov et al 1987), is the roach. The occurrence of another competitor, the crucian carp *Carassius carassius*, in the Sarysu River is characterized by single findings (Mitrofanov et al 1987). In the Bidaikskoe reservoir, the number of roach in the catches slightly exceeds the rudd; at all other sampling points, the rudd dominates. On this part of the River Sarysu at the Old Tuymoynak village, only roach was recorded in the catches. Both of these species are not dominant in the studied ichthyocenoses. In general, the ide *Leuciscus idus* and the goldfish *Carassius auratus*, with a predominance of animal food in their diet, are the most abundant everywhere. Their number in our catches was several times greater than the number of both rudd and roach. It can be stated that for the rudd in the watershed of the River Sarysu there is no evidence of any tension of either intraspecific or interspecific trophic competition due to its relatively low abundance and specific food preferences.

The pressure of predators (asp, catfish, pike *Esox lucius*, snakehead *Channa argus*) in the upper part of the basin (the Bidaikskoe reservoir and the River Zhaman-Sarysu) is moderate and slightly increased in the lower reaches (the River Sarysu). However, the diet of these species was dominated by the ide and goldfish in the upper reaches, as well as the perch *Perca fluviatilis* and the Aral stickleback *Pungitius platygaster aralensis*. Of course, secondary consumers influence the victim populations, including their growth rates. However, this influence is not decisive.

The bodies of waters studied have different formations. The Bidaikskoe reservoir is a large (135 ha) freshwater body with a complex hydrobiocenosis and a more or less constant hydrological regime. The River Zhaman-Sarysu is a section of the former Shanshar-Balykty dam: fresh, shallow water with an extremely variable hydrological regime. The section of the River Sarysu is 180 km from the town of Zhezkazgan - a series of rather large and deep permanent stretches, but with increased mineralization.

Mineralization (within reasonable limits) can be excluded from the main factors affecting the growth of rudd. In contrast, the constancy of habitat conditions (hydrological regime), with a high degree of probability, is related to the growth rate of this species. In this case, temperature stress (the effect of elevated temperatures in shallow waters) is likely to be the main factor determining growth.

Comparison with the data of other authors of the growth rates of the rudd taken from the river system under examination can only be empirical. Obviously, a number of samples from more southern regions of Central Asia are growing at a better rate than most of the Kazakhstani ones. However, in general, the groupings from these regions, as well as the basin of the Ural river, grow in about the same way. For all of them, the maximum age is 6+ years or less. Life expectancy is longer in European populations. Often, growth rates are also higher there. This is especially the case in such feeding bodies of water as the Volga delta, where the rudd has reached gigantic (for it) sizes (Mitrofanov et al 1987). But here, too, lengthening of the life cycle was not always accompanied by an increase in the growth rate. In the northernmost populations, growth rates are clearly slower.

Conclusions. The growth rate of rudd in the basin of the River Sarysu is quite average. Sexual and generational variability is practically absent. The relationship between the meaning of the calculated body length of adjacent generations is quite high in river populations. This may indicate the constancy of influencing factors and the environment as a whole. The growth curves for each of the samples have their own characteristics, which affects calculation of the von Bertalanffy equations and the Poly-Munroe growth efficiency index. According to the assessment of most of the methodological approaches, individuals from the River Sarysu and the Bidaikskoe reservoir have slightly more positive growth rates than those from the River Zhaman-Sarysu.

The main factor that has a significant effect on the growth of rudd in this waters is probably the dynamics of the hydrological regime of the bodies of water. In the reservoir and in the deeper sections of the river, the growth rate of this species is slightly higher.

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