Morphological characters of artificially induced hybrids of Siberian sturgeon, *Acipenser baerii baerii* Brandt, and green sturgeon, *Acipenser medirostris* Ayres

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Abstract. The morphometric characters of artificially induced hybrids of Siberian sturgeon, *Acipenser baerii baerii* Brandt, with green sturgeon, *Acipenser medirostris* Ayres, were examined until the fish achieved sexual maturity. The measurements encompassed 29 measurable and six meristic characters. Throughout the studied period of fish development, the greatest changes were noted in body depth (H) and head depth (HC). The characters that changed the least with respect to fish length were fork and body (l_1, l_2) lengths; the predorsal and preanal (aD, aA) lengths; and also some of the characters associated with head size – the width of the space in the lower lip (il) and the length of the barbels (lc). Until the age of 4+, the head shape changed with regard to its length, width, and the proportions of the front and back sections. It was confirmed that the fish from intensive culture in the recirculating systems exhibited greater similarity in morphometric characters to adults than did the fish from pond culture. Evidence of this was noted primarily in the characters that were the most typical of adult individuals, such as the relatively shorter head and rostrum.

Keywords: *Acipenser*, sturgeon, green sturgeon, morphology, hybrids, hybridization

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Introduction

Natural populations of sturgeon declined drastically in the last decades of the twentieth century, and many species became threatened with extinction. Overfishing and decreased spawning success stemming from river pollution and the construction of physical barriers that prevented spawning migrations led to the critical state of resources of these fishes (Gershanovich and Burtsev 1993, Birstein et al. 1997a, Barannikova et al. 2000). The decline in the numbers of sturgeon and the consequent decrease in catches has generated interest in breeding and culturing these fish under controlled conditions (Burtsev 1969, Steffens et al. 1990, Kolman 1999). Technologies were developed for the intensive culture of larvae, juvenile, and commercial-sized fish. Along with the development of intensive sturgeon culture, crossbreeding was performed in attempts to produce fish that would inherit positive characters from their parents and thus posses improved exploitation parameters (Nikolyukin 1952, Burtsev 1969). In the wild, sturgeon hybrids are fairly common, and the most frequently occurring include the Russian sturgeon, *Acipenser gueldenstaedtii* Brandt, and sterlet, *Acipenser ruthenus* L.; Russian sturgeon and stellate sturgeon, *Acipenser stellatus* Pallas; and sterlet and stellate sturgeon (Glukhov and Skosyrsky 2000). Factors facilitating their hybridization include shrinking areas of natural spawning

grounds, similarity in fish size, and corresponding spawning periods (Nikolyukin 1952, Krylova and Sokolov 1981). In recent years, the number of sturgeon hybrids created under artificial aquaculture conditions has increased (Loy et al. 1999, Ilyasov 2000, Rostami 2000, Kolman and Szczepkowski 2003). One such hybrid is that of Siberian sturgeon, *Acipenser baerii baerii* Brandt, with the green sturgeon, *Acipenser medirostris* Ayres. In the natural environment, these species inhabit different regions – the Siberian sturgeon, *A. b. baerii*, occurs in the large rivers of Siberia including the Ob, Lena, Kolyma, and Indigirka (Ruban 1999), while the green sturgeon inhabits the Asian coast from the Amur River to the Sakhalin Peninsula, the Strait of Tartary, Hokkaido, Korea, and Taiwan (Hart 1973). Hybrid of these species was created for the first time in 1995 under artificial conditions (Kolman et al. 1999). It was noted that this hybrid has a very fast growth rate (Kolman et al. 1997b), and its growth potential exceeds that of even the Siberian sturgeon, which is currently the focus of sturgeon culture in Europe (Williot et al. 2001). Additionally, the meat of this hybrid is of high nutritional quality (Jankowska et al. 2002, 2006), and it could be valuable in sturgeon culture. Currently, it is raised at many fish farms in Poland and other countries.

The literature on this subject offers morphometric descriptions of different species of sturgeon, but there is a lack of studies that describe changes in morphology that occur as the fish age. While this data is important from a scientific standpoint, it also has practical applications. Analyzing selected measurable characters at a given age permits identifying the fish body proportions that are most advantageous in terms of culturing them and their commercial worth; in other words, this can help to determine the commercial value of different fish cohorts and varieties, including those of sturgeon.

The aim of the study was to asses changes in the morphometric features of the hybrid Siberian sturgeon and green sturgeon that occur during the period prior to achieving sexual maturity.

Materials and methods

The subject of the present study was the Siberian sturgeon, *A. b. baerii*, and green sturgeon, *A. medirostris*, hybrid. The eggs were obtained from Siberian sturgeon, and the milt from green sturgeon. The fertilized eggs were imported in spring 1995 from the Sturgeon Facility in Konakovo (Russian Federation) to the Dgał Experimental Hatchery in Pieczarki. Egg incubation, initial larval rearing, and stocking larvae into recirculating systems were all done according to methods described for sturgeon fishes (Kolman et al. 1996, Kolman 1999). After the fish had reached body weights of 30 g, they were divided into two groups: one remained in the recirculating system (group O), and the second was stocked into a pond (group S). For the subsequent six years, beginning from age 1+, morphometric measurements of the fish in group S were taken. Moreover, the fish from the recirculating system were also measured at age 1+. The methods for measuring the sturgeon was described by Krylova and Sokolova (1981) and Holčik et al. (1989). Twenty-nine measurable body characters and six meristic characters were assessed (Table 1), and a total of 186 fish were measured.

The measurements of measurable characters were taken on the left side of the body. All measurements were taken *in vivo* after the fish had been anesthetized with Propiscin (Kazuń and Siwicki 2001). Younger fish (aged 1+ and 2+) were anesthetized by immersion in a solution of anesthetic at a concentration of 1-2 ml dm^{-3}, while older fish were anesthetized with a solution of Propiscin at a concentration of 8-10 ml dm^{-3} applied directly to the gills (Kolman et al. 1997a).

The measurable body characters were expressed in percentages of total body length (L), while measurable head characters were expressed in percentages of head length (C). Body weight was determined to the nearest 1 g in the smallest individuals aged 1+ and 2+ and to the nearest 10 g in older fish. Measurable characters (body lengths L, l_1, l_2; distances aD, aV, aA) were measured on a flat measuring board to the nearest 0.5 cm, while other biometric

Table 1

Measurable and meristic characters examined in Siberian sturgeon, and its hybrid with green sturgeon

Character	Feature name
Plastic features	
L	Total length
l1	Fork length
l2	Body length
aD	Predorsal distance
aV	Preventral distance
aA	Preanal distance
C	Head length
R	Rostrum length
op	Postorbital distance
o	Diameter of the eye
HC	Head depth
hCo	Head depth at the centre of eye
iO	Interorbital distance
BC	Maximum head width
bC	Head width at the upper edge of the operculum
r_r	Distance from the rostrum end to cartilaginous snout edge
r_c	Distance from the rostrum end to base of the middle barbs
lc	External barb length
SRc	Mouth width at barb base
SRr	Mouth width at cartilaginous vault
SO	Width of snout
il	Width of the lower-lip gap
H	Maximum body depth
h	Minimum body depth
pl	Length of caudal penduncle
lD	Dorsal fin lenght
hD	Height of dorsal fin
lA	Anal fin lenght
hA	Anal fih height
Meristic features	
Sd	Number of dorsal bony plates
Sl	Number of lateral bony plates
Sv	Number of ventral bony plates
D	Number of rays in the dorsal fin
A	Number of rays in the anal fin
Sp.br.	Branchial spines

measurements of body and head were done with a caliper to the nearest 0.1 mm. The meristic characters were described based on all well-developed, clearly visible fin rays, scutes, and gill rakers on the first gill arch.

Statistical analysis was performed with Statgraphics 5.0 Pl (STSC and Statistical Graphics Corporation 1989) and Statistica 8.0 Pl. The significance of mean values among the groups of fish examined was analyzed with single factor analysis of variance (ANOVA). Tukey's multiple range test was used with both even and uneven numbers of groups. The differences between groups were considered statistically significant at P ≤ 0.05.

Results

Meristic characters

The mean values of meristic characters of the hybrids of Siberian sturgeon and green sturgeon were: Sd 9.16 ± 0.82; Sl 33.05 ± 2.09; Sv 8.69 ± 0.86; D 35.67 ± 2.59; A 22.92 ± 1.91; Sp. br. 26.28 ± 1.88 (Table 2). In comparison with the Siberian sturgeon, the hybrid had fewer dorsal (Sd), lateral (Sl), and ventral (Sv) scutes, and fewer gill rakers on the gill arches (Sp.br) (Table 2). The numbers of rays on the dorsal (D) and anal (A) fins were nearly the same. No statistically significant differences between the values of the meristic characters of the hybrids in fish of different ages were confirmed (Table 3).

Measurable characters

The measurable characters changed unequally throughout the period of fish growth examined. The characters most strongly correlated with fish age were those associated with the build of the hybrid head: head length (C), rostrum length (R), postorbital distance (op), and the r_r and r_c lengths (Table 4). The characters associated strongly with fish age also included the greatest body length and dorsal (lD) and anal (lA) fin lengths. The r^2 correlation coefficient for

Table 2

Values of meristic characters of hybrids of Siberian sturgeon × green sturgeon, and Siberian sturgeon

Fish		Sd	Sl	Sv	D	A	Sp.br.
Siberian sturgeon	Mean	14.84	46.48	10.88	34.53	22.96	32.08
	SD	1.70	3.32	1.13	9.11	2.13	3.38
	Range	11-20	34-56	8-14	30-41	18-28	22-41
	Mean	9.16	33.05	8.69	35.67	22.92	26.28
	SD	0.82	2.09	0.86	2.59	1.91	1.88
Hybrids	Range	7-12	28-39	7-12	29-44	18-28	22-32

Table 3

Values of meristic characters of hybrids of Siberian sturgeon × green sturgeon in subsequent years of life

Age		Character					
		Sd	Sl	Sv	D	A	Sp.br.
1+	Mean ±SD	8.80± 0.91	33.63±2.12	8.93±0.93	34.63±2.99	22.57±2.11	26.37±1.85
	Range	7-12	29-38	7-11	29-44	18-26	23-32
2+	Mean±D	9.60±0.58	33.20±1.69	8.70±1.14	36.50±2.64	24.60±1.74	26.20±1.75
	Range	9-11	30-36	7-12	30-40	21-28	22-30
3+	Mean±SD	9.89±0.67	32.46±1.86	8.57±0.73	36.29±2.49	22.64±1.89	26.14±1.64
	Range	8-11	28-36	7-10	31-43	19-27	24-29
4+	Mean±SD	8.54±0.76	32.54±1.94	8.63±0.81	35.50±1.50	23.13±1.83	26.63±1.84
	Range	7-10	29-35	7-10	33-39	20-26	23-31
5+	Mean±SD	8.85±0.86	32.96±2.39	8.69±0.77	35.58±2.60	23.77±1.74	25.77±1.99
	Range	7-10	28-39	7-10	31-41	21-27	22-30
6+	Mean±SD	9.58±0.84	32.92±2.29	8.65±0.78	35.69±2.83	22.23±2.15	25.50±1.93
	Range	8-11	29-36	7-10	30-42	18-28	22-29

these factors were from 0.58 (lD) to 0.75 (op) (Table 4). As the fish grew, the relative lengths of the head (C) and the rostrum (R), the front of the head, decreased, while the relative length of the postorbital distance (op), the posterior section of the head, increased with fish length. The most pronounced changes in these characters were observed in the course of the first two (C) or three years (R and op), whereas differences with regard to the remaining years were statistically significant (P < 0.05). As the fish aged, the greatest relative head height (HC) and dorsal (lD) and anal (1A) fin length increased.

Comparison of measurable characters of hybrids from pond culture and recirculating systems

Hybrids aged 1+ reared in the recirculating system (group O) were larger (body weight – 2432 g; total length L – 85.8 cm) in comparison to the fish reared in ponds (group S; 232 g and 41.9 cm, respectively). Statistically significant differences were noted in the relative values of most of the measurable characters (Table 5). The greatest differences were noted in the head characters. The relative head length was greater by 14.8% in fish from group S. The rostrum in these fish was longer by 8.4%, and the postorbital distance was shorter by 12.5%. Relative eye diameter in the fish from group S was also larger by 12.2%

Table 4

Regression equations of changes in measurable characters of hybrids of Siberian sturgeon × green sturgeon

Character	Regression equations	r2
l1/L	l1 = 0.01 × L + 88.85	0.02
l2/L	l2 = 0.02 × L + 81.78	0.12
aD/L	aD = -0.01 × L + 63.92	0.07
aV/L	aV = -0.02 × L + 54.16	0.17
aA/L	aA = 0.01 × L + 67.46	0.01
C/L	C = -0.05 × L + 29.91	0.68
R/C	R = -0.11 × C + 61.88	0.71
op/C	op = 0.11 × C + 32.53	0.75
o/C	o = -0.01 × C + 6.22	0.41
HC/C	HC = 0.09 × C + 25.33	0.52
hCo/C	hCo = 0.03 × C + 17.11	0.34
iO/C	iO = 0.06 × C + 21.18	0.58
BC/C	BC = 0.08 × C + 34.40	0.50
bC/C	bC = 0.06 × C + 23.23	0.60
r_c/C	r_c = -0.12 × C + 45.45	0.64
r_r/C	r_r = -0.11 × C + 64.20	0.70
lc/C	lc = -0.00173 × C + 18.926	0.09
SRc/C	SRc = 0.04 × C + 17.57	0.39
SRr/C	SRr = 0.05 × C + 26.71	0.47
SO/C	SO = 0.03 × C + 20.82	0.34
il/SO	il = 0.05 × SO + 21.87	0.12
H/L	H = 0.04 × C + 7.46	0.70
h/L	h = 0.01 × C + 2.37	0.39
pl/L	pl = 0.01 × C + 10.52	0.17
lD/L	lD = 0.03 × L + 6.26	0.58
hD/L	hD = 0.01 × L + 6.72	0.22
lA/L	lA = 0.02 × L + 2.68	0.62
hA/L	hA = 0.01 × L + 6.87	0.15

in comparison to that in the fish from group O. Moreover, the fish from group S had lower dorsal arches, the highest relative body height (H) at 9.10 ± 0.58% L, and was 12.8% lower than the fish from the tanks. The fish from the ponds also had caudal peduncles that were 6% shorter, pectoral fins that were 12.7% shorter, and anal fins that were 18.6% shorter in comparison with individuals from the re-circulating system.

Discussion

The morphometric characters of different sturgeon species change with the periods of ontogenesis (Loy et al. 1999), and being able to recognize these changes is important both cognitively and practically. The measurable characters are also used to describe commercial value, which is determined by various characters to various degrees. The most important characters are body length (l2), head size (length, width, height), and the largest and smallest body depth (H, h) (Brylińska 2000). Morphometric data

Table 5

Comparison of measurable characters in hybrids of Siberian sturgeon × green sturgeon at age 1+ from pond culture (group S) and recirculating systems (group O). Characters with different letter indexes in the same column differ significantly statistically (P < 0.05)

Group	S	O
in % of L		
l1/L	89.76 ± 1.41^a	88.12 ± 1.27^b
l2/L	83.30 ± 1.13^a	81.48 ± 1.06^b
aD/L	63.65 ± 1.17^a	61.96 ± 0.99^b
aV/L	53.59 ± 1.07^a	51.48 ± 1.09^b
aA/L	67.93 ± 1.07^a	67.39 ± 1.16^b
C/L	27.91 ± 1.01^a	24.31 ± 0.83^b
H/L	9.10 ± 0.58^b	10.26 ± 0.57^a
h/L	2.60 ± 0.18^b	2.80 ± 0.14^a
pl/L	11.09 ± 0.91^b	11.75 ± 0.64^a
lD/L	7.49 ± 0.55^b	8.45 ± 0.60^a
hD/L	7.33 ± 0.42^a	7.54 ± 0.82^a
lA/L	3.70 ± 0.30^b	4.38 ± 0.47^a
hA/L	7.32 ± 0.46^a	7.17 ± 0.46^a
in % of C or SO		
R/C	57.75 ± 1.62^a	53.28 ± 1.40^b
op/C	36.92 ± 1.54^b	41.53 ± 1.58^a
o/C	5.69 ± 0.54^a	5.07 ± 0.42^b
HC/C	30.09 ± 1.22^a	29.79 ± 1.78^a
hCo/C	18.72 ± 1.01^a	18.14 ± 0.71^b
iO/C	23.76 ± 1.54^b	25.01 ± 0.84^a
BC/C	37.57 ± 1.98^b	40.43 ± 2.62^a
bC/C	25.58 ± 1.18^b	27.96 ± 1.09^a
r_c/C	40.51 ± 1.88^a	35.87 ± 1.69^b
r_r/C	60.05 ± 1.47^a	55.47 ± 1.43^b
lc/C	18.46 ± 1.48^a	17.63 ± 1.58^b
SRc/C	19.44 ± 0.94^b	20.02 ± 1.04^a
SRr/C	28.96 ± 1.11^b	30.11 ± 1.43^a
SO/C	22.15 ± 1.02^b	23.42 ± 1.08^a
il/SO	22.70 ± 3.25^b	25.93 ± 3.78^a

has applications in systematics, including that of sturgeon fishes (Birstein et al. 1997b, Debus 1999, Loy et al. 1999). Meristic characters are the most significant since they change only slightly with age (Prokeš et al. 1995). In sturgeons, these characters include the number of scutes in the primary rows, the number of rays in unpaired fins, and the number of gill rakers on the first gill arch (Podushka 2003).

Among the hybrids studied, the number of gill rakers on the first gill arch (Sp.br.) ranged from 22-32, which coincides with the range in the maternal species of Siberian sturgeon; however, this range was higher than those noted for green sturgeon (Artyukhin and Andronov 1990, Krylova et al. 2008). The number of dorsal (Sd) and ventral (Sv) scutes of the hybrids was lower than that in the maternal species and similar to that in the green sturgeon, while the number of lateral scutes (Sl) was between those of the parental species (Krylova et al. 2008). The number of rays in the dorsal (D) and anal (A) fins ranged from 29 to 44 and 18 to 28, which corresponded to the ranges for these characters in the parental species (Table 2, Artyukhin and Andronov 1990). The analysis of the morphometric characters of the Siberian sturgeon and green sturgeon hybrids analyzed indicated that the growth during ontogenesis was allometric. However, changes in particular characters were varied and can be divided into three basic groups: characters that changed throughout the study period until the fish attained sexual maturity, those that changed slightly during fish growth, and those that changed in the first three to four years of life.

Throughout the study period, the characters of the fish that changed the most were body depth (H) and head depth (HC). The characters that changed the least, relative to fish length, were fork length and body length (l1, l2), predorsal length and preanal length (aD, aA), and some characters associated with head size including the width of the space in the lower lip (il) and the length of the barbels (lc).

Substantial change was noted in many of the characters in the initial period of development during the first four years of life. Until the age of 3+ to 4+, the shape of the head changed relative to its length as did the proportions of the anterior and posterior sections, head and mouth width, the lowest head height, eye diameter, and the lengths of the dorsal and anal fins. The head of the hybrid became shorter, wider, and higher relative to fish length. Artyukhin and Vecsei (1999) noted similar changes in the build of

the head in a study of *Acipenser sturio* L. and the Atlantic sturgeon, *Acipenser oxyrinchus* Mitchell. These authors designated three developmental stages: the juvenile, subadult, and adult stages (in very large individuals). The first two stages are comparable with the results of the current study that identified the juvenile stage (up to age 4+) followed by the pre-adult stage. According to Ruban and Panaiotidi (1994), the changes observed in the build of the head were linked to the shortening of the rostrum, the front section of the head. Similar changes were also noted in a comparative study of 1+ and 15+ green sturgeon individuals (Krylova et al. 2008). As the relative length of the rostrum decreased with fish growth, the postorbital section comprised an increasingly large part of the head, even though the proportions relative to total fish length were maintained. In turn, Castelnaud (1991) cited in Loy et al. (1999) concluded that the morphological characters of the adult fish are already present in fish aged 1+. This indicates that the course of these changes is varied among sturgeon species. Some researchers (Loy et al. 1999) underscore the importance of the environmental conditions in which the different fish species live and the impact they have on the course of changes in shape that occur during ontogenic development. Similar conclusions can be drawn based on the current study, in which differences in the relative values of measurable characters were noted among fish of the same ages but held in ponds or recirculating systems. The decided majority of measurable characters differed significantly statistically among these fish with the largest differences in head shape, body height, and fin length. The fish from intensive rearing in recirculating systems exhibited greater similarity to adult fish in comparison with the fish reared in ponds. The characters that are most typical of adult fish such as the relatively shorter rostrum and head provide evidence of this. Similar dependencies were confirmed by Artyukhin (personal communication) for green sturgeon since cultured individuals aged 2+ were closer to wild adult fish aged 4+. Ruban and Sokolov (1986) reported similar conclusions in their analysis of the characters of Siberian sturgeon reared in heated waters and in

waters with natural temperatures. Under natural conditions fish growth is slower because of low water temperatures, and these changes occur over a longer period of time. Interference can occur in some characters, such as rostrum length, through mechanical injury sustained, for example, during feeding (Debus 1999).

Head depth was an atypical character that depended more on fish age than size. The lowest (most flattened) heads were noted in the youngest fish aged 1+ regardless of whether they were reared in ponds or tanks. This could be an adaptation of the fish to natural conditions since they inhabit rivers at this age and flattened heads are helpful in overcoming water currents.

Knowledge of the measurable characters of a species is also useful for determining meat yield indicators and the appropriateness of certain species for aquaculture. Meat yield depends on fish species, body build, age, sex, sexual maturity stage, and fish condition (Sikorski 1992, Sanders et al. 2003). Biometric characters can be used to determine body shapes that are commercially advantageous when fish have low coefficient percentage values of the biometric characters of the head and high values of predorsal length and body height (Brylińska 2000). Since some of the measurable characters change unequally as fish grow, this impacts the yield indicators in fish of different ages. In the case of the hybrids, the most commercially advantageous body proportions were achieved by the fish at age 4+, when head length (C) stabilized at 24% L, and the maximum body depth (H) was 11.82 ± 0.72% L. It is possible to conclude that the commercial value of the hybrids increased with fish growth until age 4+, and that it was the highest at this stage of ontogenic development.

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Streszczenie

Cechy morfologiczne sztucznie indukowanych mieszańców jesiotra syberyjskiego (*Acipenser baerii baerii* Brandt) z jesiotrem sachalińskim (*Acipenser medirostris* Ayres)

Badano cechy morfometryczne sztucznie indukowanych mieszańców jesiotra syberyjskiego *Acipenser baerii baerii* Brandt z jesiotrem sachalińskim *Acipenser medirostris* Ayres do momentu osiągnięcia dojrzałości płciowej. W pomiarach uwzględniono 29 cech mierzalnych ciała oraz 6 cech merystycznych. Analiza cech morfometrycznych badanej krzyżówki jesiotra syberyjskiego z jesiotrem sachalińskim wykazała allometryczny wzrost ryb w czasie ontogenezy. W całym badanym okresie życia ryb zmieniała się największa wysokość ciała (H) oraz wysokość głowy (HC). Do cech, których względne wartości w stosunku do długości ryby zmieniały się w najmniejszym stopniu należały: długość ogonowa i długość ciała (l_1, l_2), długości: przedgrzbietowa i przedanalna (aD, aA), a także niektóre cechy związane z wielkością głowy: szerokość przerwy wargi dolnej (il) i długość wąsika zewnętrznego (lc). Do wieku 4+ zmieniał się kształt głowy: względna jej długość, szerokość oraz proporcje przedniej i tylnej części. Ryby najmłodsze w grupie wieku 1+ charakteryzowały się najdłuższą głową (C) stanowiącą 27,9% długości całkowitej ryby. Ze wzrostem ryb zmniejszała się względna długość rostrum (R), a wydłużała względna przestrzeń zaoczna (op). Stwierdzono, że ryby pochodzące z intensywnego chowu w obiegu recyrkulacyjnym wykazywały większe podobieństwo cech morfometrycznych do osobników dorosłych w porównaniu z rybami ze stawów. Świadczyły o tym przede wszystkim cechy najbardziej charakterystyczne dla osobników dorosłych, takie jak relatywnie krótsza głowa i rostrum.