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The Validation of Specific Status of the Sakhalin Sturgeon *Acipenser mikadoi* (Acipenseridae) in the Light of Recent Genetic and Morphological Data*

E. D. Vasil'eva[a], V. P. Vasil'ev[b], S. V. Shedko[c], and G. V. Novomodny[d]

[a] *Zoological Museum, Moscow State University, Bol'shaya Nikitskaya 6, Moscow, 125009 Russia*

[b] *Severtsov Institute of Ecology and Evolution, Russian Academy of Sciences, Leninskii prospect 33, Moscow, 119071 Russia*

[c] *Institute of Biology and Soil Sciences, Far East Branch of Russian Academy of Sciences, Prospect Stoletiya Vladivostoka 159, Vladivostok, 690022 Russia*

[d] *Khabarovsk branch of FGUP TINRQ-Center, Amurskiy boulevard 13A, Khabarovsk, Russia*

e-mail: vas_katerina@mail.ru

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Abstract—The taxonomic relations between the Sakhalin and North American green sturgeons were re-evaluated based on afresh conducted comparative morphological analysis of both sturgeons, as well as a renovation of literature cytogenetic, molecular and morphological data. The comparative analysis of different data sets demonstrates the validity of the Sakhalin sturgeon *A. mikadoi* which differs from the North American green sturgeon *A. medirostris* in the karyotype structure, the nuclear DNA content value, and several morphological characters. The key for their identification is presented.

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The Sakhalin sturgeon was described as a new species *Acipenser mikadoi* Hilgendorf off the North Japan coast (Hilgendorf, 1892). But only a few following authors agreed with independent specific status of this sturgeon distributed in western part of the Pacific Ocean (Schmidt, 1904; Jordan and Snyder 1906). While the others considered the Sakhalin sturgeon to be conspecific with the North American green sturgeon *A. medirostris* Ayres, 1854 (Berg 1911, 1916, 1923, 1932, 1948; Soldatov, 1915; Soldatov and Lindberg 1930; Taranetz, 1937; Nikolsky, 1956; Masuda et al., 1984) or attributed this form to the Asian subspecies—*A. medirostris mikadoi* (Lindberg, 1947; Schmidt, 1950; Lindberg and Legesa, 1965). Lindberg and Legesa (1965) mentioned that the Sakhalin sturgeon is closed to the North American green sturgeon, but they considered that subspecies rank of the Sakhalin sturgeon was confirmed by observed differences in the variability and mean values of five meristic characters: numbers of dorsal and anal fin rays, and numbers of dorsal, lateral, and ventral scutes. It should be noted that these authors used literature data and included specimens from Japan waters in *A. medirostris mikadoi* while *A. medirostris medirostris* was represented in their study by specimens from San-Francisco, California and also from the Bering Sea, namely the specimen from the Olyutorsky Bay previously had been studied by Andriyashev and Panin (1953). The main differences between aforementioned samples were observed in numbers of anal fin rays and lateral scutes: 18–27 (mean value 23.0) and 25–30 (mean value 27.9) in *A. medirostris medirostris*, and 25–31 (28.9) and 27–36 (31.3) in *A. medirostris mikadoi*, accordingly (Lindberg and Legesa, 1965). In contrast, Artjukhin and Andronov (1990) concluded that comparative morpho-ecological analysis of both forms of issue did not give any reasons for their separation into two different subspecies.

The special attention to the taxonomic relations of the North American green and Sakhalin sturgeons resumed after Birstein and co-authors (1993) who have determined DNA content in the Sakhalin sturgeon. According to their study DNA content in the Sakhalin sturgeon is very high: "in two times higher" (13.93–14.73 pg/nucleus) than in the octoploid sturgeons including the North American green sturgeon characterized by 8.82 pg/nucleus (Blacklidge and Bidwell, 1993). These data resulted in conclusion on the 16-ploid level and 500-chromosome karyotype in the Sakhalin sturgeon (Birstein et al., 1993). After aforementioned publication the Sakhalin sturgeon is treated as 500-chromosome species by several authors (Birstein and Bemis, 1997; Birstein et al., 1997a, 1997b; Birstein and DeSalle, 1998; Ludwig et al., 2000, 2001; Birstein, 2005). Since the North Ameri-

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can green sturgeon belongs to octoploid sturgeon species with about 250 chromosomes (Van Eenennaam et al., 1999) Birstein and co-authors (1993) concluded that "Asian form of *A. medirostris* is at least a subspecies, *A. medirostris mikadoi*, or even a species, *A. mikadoi*." Further molecular analysis confirmed "a profound genetic difference between *A. medirostris* and *A. mikadoi*" (Birstein and DeSalle, 1998). As a result, some authors accepted the validity of *A. mikadoi* (Birstein, 1993a, 1993b; Birstein et al., 1997a, 1997b; Birstein and Bemis, 1997; Vasil'eva, 1999; 2004a; Froese and Pauly, 2009), while the others staid on traditional Berg's (1948) taxonomic position (Sokolov, 1998; Reshetnikov, 2002; Novomodny et al., 2004; Bogutskaya and Naseka, 2004).

Further morphological investigations on the North American green and Sakhalin sturgeons demonstrated contradictory results. On the one hand, Artyukhin and co-authors (2007) considered them to be quite similar in studied morphological characters and ecological features and concluded that these similarities indicate them to belong to the same species. On the other hand, North and co-authors (2002) found considerable differences between North American and Asian populations in some morphometric characters, especially measures related to snout length, but mentioned the problems in comparison of data obtained by different authors. Similar results were obtained by craniometric analysis of different Acipenserid species that revealed *A. mikadoi* to be more similar to *A. baerii* Brandt, whereas *A. medirostris* was more similar to *A. brevirostrum* Lesueur (Vasil'eva, 2004b, 2009).

In contrast to the molecular phylogeny presented by Birstein and DeSalle (1998), the study of the mtDNA by Ludwig and co-authors (2000) demonstrate Sakhalin and North American green sturgeons to be very closely related: apart from two silent nucleotide exchanges observed within entire cyt-*b* sequences, both species differ by only one nucleotide insertion/deletion in the central repeat units within control region. Both species is clustered together with *A. transmontanus* Richardson, whereas according to Birstein and DeSalle (1998) *A. mikadoi* does not belong to "A. schrenckii–*A. transmontanus cluster*". The analysis of individual cytochrome *b* sequences from different Acipensriform species performed by the employment of Gene-bank data demonstrates *A. mikadoi* and *A. medirostris* as related species clustered together with *A. transmontanus* (Fontana et al., 2001). Whereas on the phylogenetic tree based on cytochrome-*b* gene sequences from fresh materials (Ludwig et al., 2001) these forms represent monophyletic lineage with high quartet-puzzling support 100% and they are clustered together with *Huso dauricus* (Georgi). As a result of the study of mtDNA control regions Zhang and co-authors (2001) concluded the Sakhalin and North American green sturgeons to be conspecific because their low genetic differences.

On the basis of microsatellite analysis Ludwig and co-authors (2001) "confirmed" that *A. mikadoi* is octoploid species with about 500 chromosomes and classified *A. medirostris* as tetraploid species with about 250 chromosomes. Their study revealed differences between North American green and Sakhalin sturgeons in allelic band patterns at least at one locus Afu-34, which demonstrated disomic pattern in *A. medirostris* and tetrasomic pattern in *A. mikadoi* (Ludwig et al., 2001). High value of DNA content of erythrocytes in the Sakhalin sturgeon was confirmed by further studies: flow cytometric histograms for four Sakhalin sturgeons caught off Hokkaido and 30 cultured specimens of *A. schrenckii* Brandt demonstrated that mean value of *A. mikadoi* was about 1.14 times higher than mean value of *A. schrenckii* (Omoto et al., 2004). Since DNA content value obtained in *A. schrenckii* by flow cytometry varies from 11.59 to 11.73 pg (Yin et al., 2004), these data confirm DNA content in the Sakhalin sturgeon to be significantly higher than in the North American green sturgeon; similar results were obtained by cytophotometry of the Sakhalin sturgeon cells (Viashnyakova et al., 2008).

Thus, the main conventional opinion resulted from aforementioned data was that *A. mikadoi* and *A. medirostris* are very closely related forms differed in DNA content only, and this difference is caused by different ploidy levels, namely tetraploidy with about 250 chromosomes in *A. medirostris* and octoploidy with about 500 chromosomes in *A. mikadoi*. But the newly obtained data on the karyotype structure of *A. mikadoi* demonstrate this fish as a tetraploid species (Vasil'ev et al., 2008, 2009) and thus refuse aforementioned difference in ploidy levels and recalls the question on taxonomic relations and diagnostic characters of this form and the North American green sturgeon.

The purpose of this study is to re-evaluate taxonomic relations between the Sakhalin and North American green sturgeons based on afresh conducted comparative morphological analysis of both sturgeons, as well as a renovation of literature genetic and morphological data.

MATERIAL AND METHODS

Morphological characters previously have been used in comparative studies of the Sakhalin and North American green sturgeons (Andriashev and Panin, 1953; Nikolsky, 1956; Lindberg and Legesa, 1965; Artyukhin and Andronov, 1990; North et al., 2002, Artyukhin et al., 2007) were examined in six green sturgeon specimens from the Zoological Institute RAN (ZISP) collection: 12938 (Japan, Hakodate, 1 spec.), 49833 (Tumnin River, 2 spec.), 50527 (Tumnin River, 2 spec.), 33033 (Bering Sea, 1 spec.); their total body length (L_T) values are presented in the table.

Ranges and means (in brackets) for some morphometric characters in Asian and North American populations of green sturgeons

Character	Asian green sturgeon *A. mikadoi*			North American green sturgeon *A. medirostris*		
	This paper ($n = 5$)	Soldatov, 1915 ($n = 6$)	Artyukhin and Andronov, 1990 ($n = 7–8$)	Andriyashev and Panin, 1953/this paper ($n = 1$)	North et al., 2002 ($n = 50$)	North et al., 2002 ($n = 1$)
Total body length (L_T), cm	14.1–70.5 (47.1)	77–140 (97.0)	148–180 (163)	112/110	125–170 (148)	198
Head length (*HL*), % L_T	23.1–27.5 (25.6)	21.8–24.7 (23.8)	22.4–24.3 (23.3)	21.4/20.2	16.2–21.6 (18.8)	19.2
Snout length, % L_T	–	10.2–13.4 (12.1*)	10.0–12.0 (10.9)	9.3**/–	5.0–9.9 (7.4)	7.6
Length of snout to barbells, % *HL*	32.5–39.0 (34.8)	27.2–36.5 (32.4)	26.2–30.7 (27.7)	22.9/23.4	12.4–24.8 (19.2)	22.1
Length of barbells to mouth, % *HL*	18.9–25.3 (21.8)	17.1–22.9 (19.6)	17.8–21.3 (19.4)	–/21.1	21.3–29.3 (26.0)	16.6

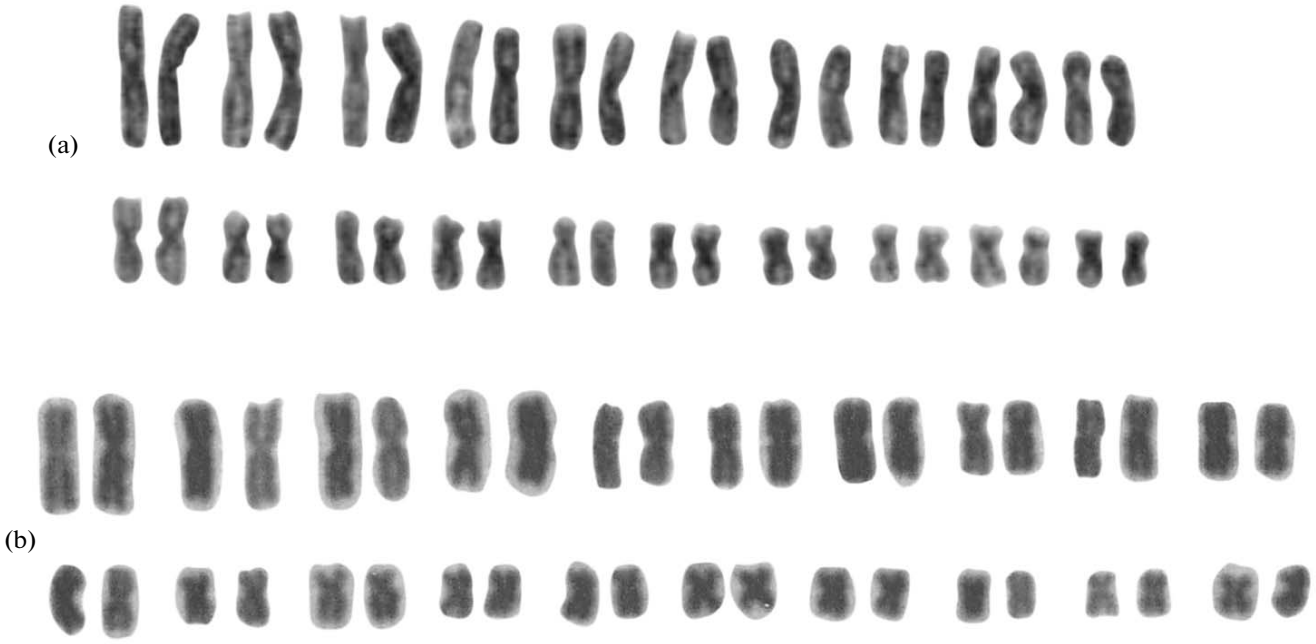
* Data recalculated by the authors from Soldatov, 1915.
** Data recalculated by the authors from Andriyashev and Panin, 1953.

RESULTS AND DISCUSSION

The comparative morphological analysis of six museum specimens from Asian (=Sakhalin sturgeon) and North American populations of the green sturgeons, as well as of available morphological data from literature (Soldatov, 1915; Andriashev and Panin, 1953; Nikolsky, 1956; Lindberg and Legesa, 1965; Artyukhin and Andronov, 1990; North et al., 2002; Artyukhin et al., 2007; Artjukhin, 2008) performed by taking into consideration some methodological uniformity in different publications, confirms considerable overlapping of meristic characters from *A. mikadoi* and *A. medirostris*, that was observed by previous authors (Artyukhin and Andronov, 1990; North et al., 2002; Artyukhin et al., 2007; Artjukhin, 2008). But at the same time it should be noted that the number of ventral scutes in the Sakhalin sturgeon varies from 5 to 10, but usually does not exceed 9, and more often specimens with 7–8 scutes occur. Whereas in the North American green sturgeon the number of ventral scutes varies from 7 to 12 (5–6 scutes were found by Deng (2000) only in young-of-year specimens with more probably undeveloped scutes), usually exceed 9, with enough large number of specimens having 10 or more ventral scutes. The number of gill rakers varies in the Sakhalin sturgeon from 18 to 21, usually less than 20, while in the North American green sturgeon the number of gill rakers varies from 15 to 26, and specimens having more than 20 gill rakers are enough usual. Thus, according to these data the Sakhalin sturgeon should be characterized by the presence of usually not more than 9 ventral scutes and less than 20 gill rakers versus usually more than 9 ventral scutes and more than 20 gill rakers in the North American green sturgeon.

Among morphometric characters studied by North and co-authors (2002) only four features demonstrated most prominent differences between Asian and North American populations of green sturgeons (table). The analysis of the data calculated for these characters in recent studies and previous publications, including the data presented by Artyukhin and Andronov (1990) for two juvenile specimens with L_T50 and 58 cm, revealed that relative values of head length, snout length, and length of snout to barbels decrease in larger green sturgeon specimens; however, specimens of *A. mikadoi* and *A. medirostris* with more or less similar total body length demonstrate stable and appreciable differences in three aforementioned metric characters (table). Specimens of the Sakhalin sturgeon have noticeably longer head, snout, and distance from snout to barbels than specimens of the North American green sturgeon of the same size; whereas the distance from barbels to mouth are longer in the last species (table). Based on available data, barbels are always nearer to the mouth than to the tip of snout in the Sakhalin sturgeon, and the ratio of these distances in this species is closed to 1.5; whereas in the North American green sturgeon barbels are often nearer to the tip of snout or about equidistant between the tip of snout and the mouth, if they are closer to the mouth, the ratio of these distances does not exceed 1.3. It should be mentioned, however, that aforementioned conclusion is based on the measurements obtained in this study and presented for both sturgeons in literature. However, some informative resources present the same state of this character for both forms of green sturgeons, namely, "barbels are closer to the mouth than to the tip of the snout" (*FAO*…, 2000–2008; *Petition*…, 2001). Possibly, this incorrect information results from the extension of the state peculiar for the Sakhalin sturgeon on both species.

Revealed morphological differences seem sufficient for specific level of divergence among sturgeons. It should be stressed that snout length and the position of barbels belong to the main diagnostic features sepa-



The first 20 pairs of the largest chromosomes in the karyotypes of *A. mikadoi* (a) according to Vasil'ev et al., 2009 and *A. medirostris* (b) according to Van Eenennaam et al., 1999.

rating *A. sturio* Linnaeus from three other European species, namely *A. naccarii* Bonaparte, *A. persicus* Borodin, and *A. gueldenstaedtii* Brandt et Ratzeburg (Sokolov, 1989), and the divergence in external morphological characters traditionally used in sturgeons is certainly less prominent in comparison of two last mentioned species sympatrically distributed in the Black and Caspian seas than between allopatric *A. mikadoi* and *A. medirostris.*

Moreover, in spite of rejection of previous conception on high differences in chromosome numbers between *A. mikadoi* and *A. medirostris,* recent karyological data present new diagnostic characters and thus a new evidence for taxonomic independence of both aforementioned sturgeons. According to these data the karyotype of the Sakhalin sturgeon includes 262 ± 4 chromosomes; the number of biarmed chromosome is 80, and the number of chromosome arms (NF)—342 ± 4 (Vasil'ev et al., 2008, 2009). Whereas, the karyotype of *A. medirostris* includes 249 ± 8 chromosomes; the number of biarmed chromosomes is 96, and NF—345 ± 8 (Van Eenennaam et al., 1999). In addition, the first 20 pairs of the largest biarmed chromosomes from the karyotype of the Sakhalin sturgeon are represented by at least nine submetacentric pairs and 11 metacentric pairs, whereas the same chromosomes from the karyotype of the North American green sturgeon include not more than four pairs of submetacentrics and 14 of metacentrics (figure). These differences are enough substantial and confirm taxonomic independence of both species.

Apart of karyological and morphological differences, *A. mikadoi* significantly differs from *A. medirostris* in the DNA content and in allelic patterns at microsatellite locus Afu-34 (Birstein et al., 1993; Ludwig et al., 2001; Omoto et al., 2004).

In addition to the discussion of taxonomic relations it should note that the specimen from the Bering Sea (Olyutorsky Bay, ZISP # 3303), previously studied by Andriyashev and Panin (1953) and then in this study, undoubtedly belongs to North American *A. medirostris* as believed some previous authors (Andriyashev and Panin, 1953; Lindberg and Legeza, 1965; Colway and Stevenson, 2007), but not to Asian *A. mikadoi* as it has been erroneously defined by Artyukhin and coauthors (2007) and reflected later in incorrectly presented range of the Sakhalin sturgeon (Shmigirilov et al., 2006; Froese and Pauly, 2009). Its attribution to *A. medirostris* is proved by its short head, snout, and length from snout to barbells (table), barbells shifted to the snout tip and the presence of 22 gill rakers and 10 ventral scutes. This conclusion is also confirmed by high migratory activity well known for the North American green sturgeon which can cover considerable distances in the ocean (Morrow, 1980; *COSEWIC* …, 2004) and sometimes traveling more than 150 km upstream to spawn (*Petition* …, 2001). As a result the range of *A. medirostris* reaches to the north as far as Aleutian Islands and Alaska (Israel et al., 2004; Froese and Pauly, 2009), that is confirmed by recent findings (Colway and Stevenson, 2007).

In conclusion, the next main state should be noted: the Sakhalin sturgeon and the North American green

sturgeon are close related based on mtDNA sequences, but they differ in the karyotype structure, the nuclear DNA content value, and several morphological characters and should be considered independent species *A. mikadoi* and *A. medirostris*. The key for their identification is presented below.

1. Barbels nearer to the mouth than to the tip of snout, the ratio of these distances is closed to 1.5; usually not more than 9 ventral scutes; generally less than 20 gill rakers … *A mikadoi*.

2. Barbels often nearer to the tip of snout or about equidistant between the tip of snout and the mouth, if they closer to the mouth, the ratio of these distances does not exceed 1.3; usually more than 9 ventral scutes; generally more than 20 gill rakers … *A. medirostris*.

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