Morphology and taxonomy of the Atlantic sturgeon, *Acipenser sturio* from Spain

Benigno ELVIRA[1] and Ana ALMODÓVAR[2]

[1] *Department of Animal Biology I, Faculty of Biology, University Complutense of Madrid, E-28040 Madrid, Spain; e-mail: belvira@eucmax.sim.ucm.es*

[2] *Department of Ecology, Agricultural Research Institute of Madrid (I.M.I.A.), El Encín, E-28800 Alcalá de Henares, Madrid, Spain; e-mail: ana.almodovar@encin.alcala.es*

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Abstract. A total of 31 preserved specimens of Atlantic sturgeon *Acipenser sturio* from 16 Spanish Museum collections were morphologically studied. These sturgeons were caught as early as the 19th century until 1988. For 19 specimens, the site of capture is known, whereas the others have presumably been encountered in Spanish rivers or seas. Seven specimens were damaged or in very bad condition, but 24 specimens (Sl = 66.5 – 1640 mm) were measured in detail. The data matrix of 39 morphometric and 12 meristic characters was studied using standard numerical taxonomic techniques, resulting that *A. sturio* is the only native sturgeon species in the region, with a most recent record reported in 1992.

Key words: biometrics, conservation, distribution, fish, morphometry

Introduction

The Atlantic sturgeon *Acipenser sturio* L., 1758, is considered to be the only sturgeon species native to the Iberian Peninsula accepted by recent authors (Almaça 1988, Holčík 1989, Doadrio et al. 1991, Elvira et al. 1991a, 1991b, Elvira & Almodóvar 1993, Pereira 1995). Nevertheless, Garrido-Ramos et al. (1997) considered two sturgeon species as being native to Spain: *A. sturio* and *Acipenser naccarii* Bonaparte, 1836, usually recognized as an Adriatic endemism (Tortonese 1989, Birstein & Bemis 1997).

A. sturio is a highly threatened species throughout its range (Lepage & Rochard 1995, Debus 1995, 1996, Birstein et al. 1997) and several efforts on recovering its natural populations are in progress in Europe (Elvira & Gessner 1996), especially developed in France (Williot et al. 1997). However, a good knowledge of the taxonomy and regional variations is especially important for recovery projects (Birstein et al. 1998). As *A. sturio* has almost disappeared in the wild, more work should be done using museum collections (Birstein & Bemis 1997). The last known native sturgeon in Spain was captured in 1992 (Elvira & Almodóvar 1993).

In a former review, Elvira et al. (1991a) reported 10 specimens housed in four Spanish collections. Garrido-Ramos et al. (1997) studied 15 preserved specimens from Spanish waters, four specimens from Portugal and one specimen of *A. naccarii* from a fish farm. For our study, 31 preserved specimens of *A. sturio* housed in 16 Spanish museums were analysed, together with 13 specimens of *A. naccarii* of an Adriatic origin. The aim of the present study is to analyse the morphology of the Spanish native sturgeons in order to confirm their taxonomic status.

Material and Methods

In total, 31 preserved (19 stuffed, 12 preserved in alcohol) Atlantic sturgeons *A. sturio* of 16 Spanish museums were examined. The site of capture was known for 19 specimens (Fig. 1), whereas the rest are presumably to originate from Spanish waters, and were labelled "Spain?". Comparative material included three preserved specimens of *A. sturio* from central Europe, and 13 *A. naccarii* of an Adriatic origin, most of them from fish farms (Table 1).

Some morphological qualitative features such as skin pattern (Berg 1948, Magnin 1962, Artyukhin 1995), usually accepted as diagnostic characters in sturgeons, were studied. Additionally, 39 morphometric and 12 meristic characters were determined according to Holčík et al. (1989a) and subjected to Principal Components Analysis. For this purpose, the morphometric characters were divided by total length, whereas meristic characters were log-transformed. All the characters were standardized (Sokal 1961) before computation of correlation and average taxonomic distance coefficients among individuals in order to pool the information from different characters into a comparable scale.

Principal Components Analysis (PCA), using a correlation matrix, was employed to evaluate meristic and shape variation. The data matrix of metric and meristic features of different samples was used. A minimum spanning tree (Gower & Rose 1969) was also performed from the distance matrix.

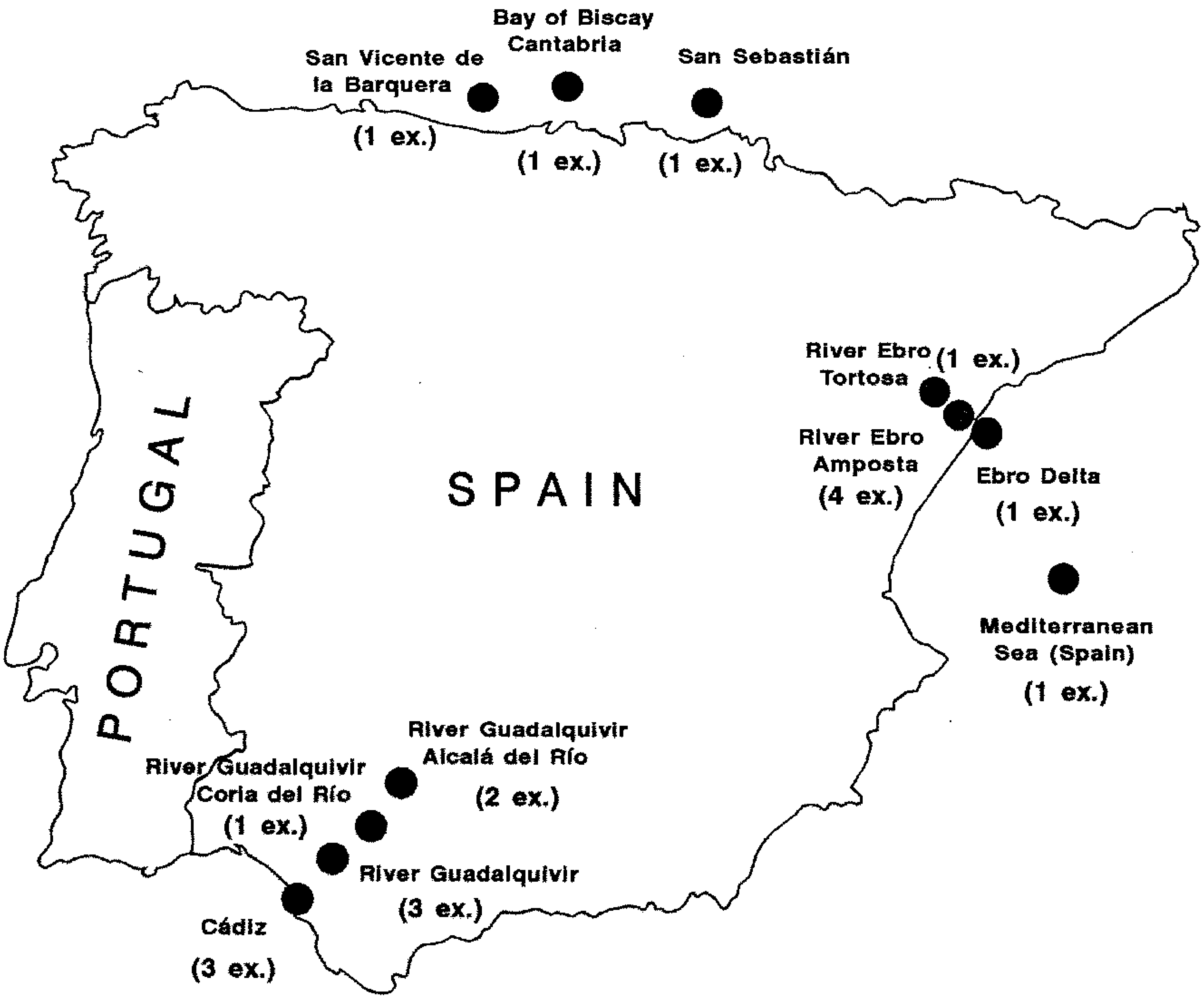

Fig. 1. Map with Spanish localities of native sturgeon *A. sturio* used in this study. See Materials examined in Table 1.

Metric and meristic characters of the specimens formerly assigned by PCA to groups corresponding respectively to *A. sturio* and *A. naccarii* were subjected to an univariate analysis. Since there is controversy surrounding the use of ratios to adjust for size variation

Table 1. Specimens of *Acipenser* spp. (those in square brackets were used in morphometric analysis) examined. The institutional abbreviations follow Leviton et al. 1985, Leviton & Gibbs 1988 when possible.

Acipenser sturio

MNCN uncat. (IFIE 7bis) [S1]; River Ebro, Amposta, Tarragona; 9 December 1951; Sl=66.5 mm; alcohol.

MNCN 1579–1581 (3 ex.) [S2-S4]; R. Ebro, Amposta, Tarragona; Leg. E. Boscá; 226, 303 and 325 mm; alcohol.

MNCN 1582 [S5]; R. Guadalquivir; Leg. T.E.A. Classen; 208 mm; alcohol.

MNCN 1583 [S6]; R. Ebro, Tortosa, Tarragona; Leg. E. Boscá; 242 mm; alcohol.

MNCN 44145 [S7]; Mediterranean Sea, Spain; 755 mm; stuffed.

VBCM uncat. [S8]; no data, Spain?; 455 mm; stuffed.

Estación Biológica de Doñana, Sevilla, EBD 8173; R. Guadalquivir, Alcalá del Río, Sevilla; 12 April 1974; Tl=1755 mm; alcohol.

EBD 8174; R. Guadalquivir, Alcalá del Río, Sevilla; 11 May 1975; Tl=1520 mm; stuffed.

EBD 8401; R. Guadalquivir, Coria del Río, Sevilla; Winter 1981; Tl=1610 mm; alcohol..

Instituto Aguilar y Eslava, Cabra, Córdoba, IAEC uncat. [S9]; R. Guadalquivir; 1880; 1150 mm; stuffed.

Estación de Ecología Acuática, University of Sevilla, EEAUS uncat. [S10]; R. Guadalquivir; 1965–67; Leg. J.M. Pascual; 288 mm; alcohol.

Department of Animal Biology, University of Sevilla, DABUS uncat. (3 ex.); Cádiz; 189, 277 and 300 mm; stuffed.

Museo del Cantábrico, Santander, Cantabria, MMCS 3/Vc/171 [S11]; Bay of Biscay, Cantabria; 1914; Leg. Linares; 430 mm; alcohol.

MMCS 3/Vc/1210 [S12]; San Vicente de la Barquera, Cantabria; 10 June 1988; 1205 mm; stuffed.

Museu de Zoologia, Barcelona, MZB 82–5337 [S13]; Ebro Delta, Tarragona; Leg. L. Soler; 1285 mm; stuffed.

MZB 82–5340 [S14]; no data, Spain?; 460 mm; stuffed.

MZB 82–5342 [S15]; no data, Spain?; 730 mm; stuffed.

MZB 95–0105 [S16]; no data, Spain?; 835 mm; stuffed.

Department of Animal Biology, University of Barcelona, DABUB uncat. [S17]; no data, Spain?; 680 mm; alcohol.

Department of Animal Biology, University of Granada, DABUG uncat.; no data, Spain?; Tl = aprox. 1600 mm; stuffed.

DABUG; no data, Spain? [S18]; 675 mm; stuffed.

Museu Etnogràfico-Missional dels Caputxins de Catalunya, Barcelona, MEMCCB uncat. [S19]; no data, Spain?; 970 mm; stuffed.

Instituto de la Sagrada Familia, Puerto de Santa María, Cádiz, ISFPSM uncat. [S20]; no data, Spain?; 1640 mm; stuffed.

Instituto Cardenal Cisneros, Madrid, ICCM uncat. [S21]; no data, Spain?; 1640 mm; stuffed.

Museo Luis Iglesias, Santiago de Compostela, A Coruña, MLISC uncat. [S22]; no data, Spain?; 1865–70; Leg. V. López Seoane; 1430 mm; stuffed.

Museo P.P. Paúles, Villafranca del Bierzo, León, MPVB uncat. [S23]; no data, Spain?; 1460 mm; stuffed.

Departament of Zoology and Ecology, University of Navarra, Pamplona, DZEUN uncat. [S24]; Bay of Biscay, San Sebastián, Guipúzcoa; 21 May 1975; Leg. M. Ibáñez; 945 mm; alcohol.

Acipenser sturio (central Europe)

VBCM uncat. [S25]; no data; Leg. V. Frič, Prague; 380 mm; alcohol.

DZEUN uncat. [S26]; North Sea; 480 mm; stuffed.

Seminario Menor, Santiago de Compostela, A Coruña, SMSC uncat. [S27]; no data, France?; 1000 mm; stuffed.

Acipenser naccarii

VBCM uncat. (3 ex.); fish farm; 75, 75 and 100 mm; alcohol.

EEAUS uncat. (2 ex.) [N1-N2]; fish farm; 177–190 mm; alcohol.

EEAUS uncat. (2 ex.) [N3-N4]; fish farm; 650–690 mm; frozen.

EBD uncat. (4 ex.) [N5-N8]; fish farm; 405, 1120, 1120 and 1190 mm; frozen.

SMF uncat. [N9]; Saxenstör 94; 6 June 1995; 156 mm; alcohol.

SMF 7634 [N10]; Neapel; 21 July 1924; 485 mm; alcohol.

(M a y d e n & K u h a j d a 1996) in metric characters, an ANCOVA (Z a r 1999) using the total length as covariate was used to test for significant differences. That is why the morphometric ratios proposed by B e r n i n i & N a r d i (1989) and G a r r i d o - R a m o s et al. (1997) were not used, since they are affected by allometry. Significant differences between species for meristic characters were identified using the Kruskal-Wallis test (Z a r 1999). For the multivariate and univariate analyses, we employed STATISTICA (S t a t S o f t 1996) and NT-SYSpc (R o h l f 1998) packages. Unless otherwise indicated statistical significance occurred for $P < 0.05$.

Results

Metric and meristic features of the Spanish sturgeons (Table 2) are similar to those formerly described for *A. sturio* (H o l č í k et al. 1989b).

PCA was calculated from the correlation matrix among all characters and 27 specimens of *A. sturio* and 10 specimens of *A. naccarii*. The projections of the specimens onto the first and second (Fig. 2a) and second and third (Fig. 2b) principal components showed that *A. naccarii* clustered together and were well separated from the *A. sturio*. Table 3 includes the characters correlations for each of the three first components computed from the pooled within-individuals correlation matrix. The first three components contained positive and negative correlations of variable magnitude and were interpreted as vectors of shape, essentially free of size. The variance explained by the first three components was 56.6 %. The first component indicated the presence of differences in head-shape (lc, prO, io, lb, s-m, s-mc, s-b, b-mc), position (pP, P-V, P-A) and size of fins (hD, lP, lV). Characters loading most heavily on the second component included meristic (Sp.br., Fu, SL), and metric characters related to fin positions (pD, pV) and length of caudal peduncle (lpc). The third component was mainly correlated with head width (lac) and unbranched rays of caudal fin (Cu). This variation resulted in complete separation of the two species along PC2 (Fig. 2). The connection of individuals on the shortest minimally connected network does not indicate any change in the relative distance between specimens (Fig. 2).

Between *A. sturio* and *A. naccarii*, 10 morphometric characters were significantly different (ANCOVA, Table 4); eight of them were related with head distances, mainly the snout shape and the width of mouth. Only three meristic characters were significantly different (Kruskal-Wallis) between *A. sturio* and *A. naccarii*: numbers of gill rakers ($H = 11.870$, $df = 20$, $P = 0.0006$), dorsal scutes ($H = 8.465$, $df = 42$, $P = 0.004$) and lateral scutes ($H = 7.590$, $df = 42$, $P = 0.006$).

Discussion

One of the best diagnostic external characters for *A. sturio* is the presence of skin between scute rows armoured with rhombic plates arranged in oblique rows. This skin pattern is more or less evident, but it is usually patent in large specimens. B e r g (1948), M a g n i n (1962) and H o l č í k et al. (1989b) described this feature, which is a synapomorphy for the Atlantic Sea sturgeons *A. sturio* and *A. oxyrinchus* Mitchill, 1815 (A r t y u k h i n 1995). On the contrary, between the rows of scutes in *A. naccarii*, the skin is armoured with small bony plates, granuliform or flat and stellate of variable size and shape (T o r t o n e s e 1989). Unfortunately, skin pattern was not analysed by G a r r i d o - R a m o s et al. (1997). Thus,

Table 2. Metric and meristic characters for 24 *A. sturio* (N = 9 for Sp.br.) from Spain. All metric characters (except Total length) are expressed as divided by Tl. Abbreviations follow H o l č í k et al. (1989a).

Character		Range	Mean±SD
Total length	Tl	80.0–1940.0	874.2±554.3
Fork length	Fl	0.875–0.959	0.914±0.027
Standard length	Sl	0.807–0.935	0.869±0.039
Length of head	lc	0.175–0.300	0.220±0.026
Preorbital distance	prO	0.064–0.161	0.103±0.021
Horizontal diameter of eye	Oh	0.007–0.032	0.020±0.005
Postorbital distance	poO	0.086–0.121	0.097±0.008
Predorsal distance	pD	0.642–0.772	0.692±0.036
Prepectoral distance	pP	0.191–0.317	0.234±0.026
Preventral distance	pV	0.555–0.657	0.594±0.030
Preanal distance	pA	0.669–0.819	0.734±0.043
Length of caudal peduncle from dorsal fin	lpcd	0.087–0.131	0.105±0.012
Length of caudal peduncle from anal fin	lpc	0.065–0.109	0.093±0.012
Distance between pectoral and ventral fins bases	P–V	0.256–0.381	0.331±0.033
Distance between pectoral and anal fins bases	P–A	0.334–0.552	0.471±0.050
Distance between ventral and anal fins bases	V–A	0.069–0.143	0.107±0.017
Length of dorsal fin	lD	0.062–0.103	0.081±0.010
Depth of dorsal fin	hD	0.053–0.092	0.075±0.012
Length of pectoral fin base	lPbs	0.028–0.072	0.038±0.008
Length of pectoral fin	lP	0.068–0.146	0.114±0.019
Length of ventral fin base	lVbs	0.029–0.050	0.037±0.006
Length of ventral fin	lV	0.040–0.087	0.064±0.013
Length of anal fin base	lA	0.029–0.077	0.047±0.010
Depth of anal fin	hA	0.043–0.128	0.076±0.020
Body depth	H	0.086–0.160	0.122±0.018
Minimum body depth	h	0.024–0.039	0.033±0.004
Head depth (at centre of eye)	hco	0.050–0.069	0.060±0.006
Head depth (at nape)	hc	0.090–0.114	0.099±0.007
Width of mouth	lam	0.030–0.061	0.045±0.008
Internal width of mouth	laim	0.021–0.051	0.036±0.008
Head width	lac	0.080–0.126	0.107±0.010
Interorbital distance	io	0.062–0.078	0.070±0.004
Width of snout at level of mouth	lasa	0.074–0.108	0.086±0.008
Width of snout at base of barbels	lab	0.034–0.085	0.050±0.016
Length of barbel	lb	0.013–0.048	0.029±0.010
Distance between tip of snout and mouth	s–m	0.081–0.177	0.119±0.024
Distance between tip of snout and cartilaginous arch	s–mc	0.076–0.175	0.114±0.025
Distance between tip of snout and barbels	s–b	0.038–0.106	0.062±0.017
Distance between barbels and cartilaginous arch	b–mc	0.033–0.069	0.052±0.010
Unbranched rays of dorsal fin	Du	35–51	39.6±3.9
Unbranched rays of pectoral fin	Pu	23–45	35.5±4.1
Unbranched rays of ventral fin	Vu	21–30	26.0±2.4
Unbranched rays of anal fin	Au	23–38	26.2±3.2
Unbranched rays of caudal fin	Cu	69–105	84.6±9.7
Fulcrae	Fu	22–31	26.6±2.6
Branchial spines (gill rakers)	Sp.br.	14–22	17.2±3.2
Dorsal scutes	SD	9–14	12.0±1.2
Lateral scutes (left)	SL–left	25–38	33.2±2.9
Lateral scutes (right)	SL–right	24–39	33.7±3.1
Ventral scutes (left)	SV–left	9–13	11.0±0.9
Ventral scutes (right)	SV–right	9–13	10.8±1.0

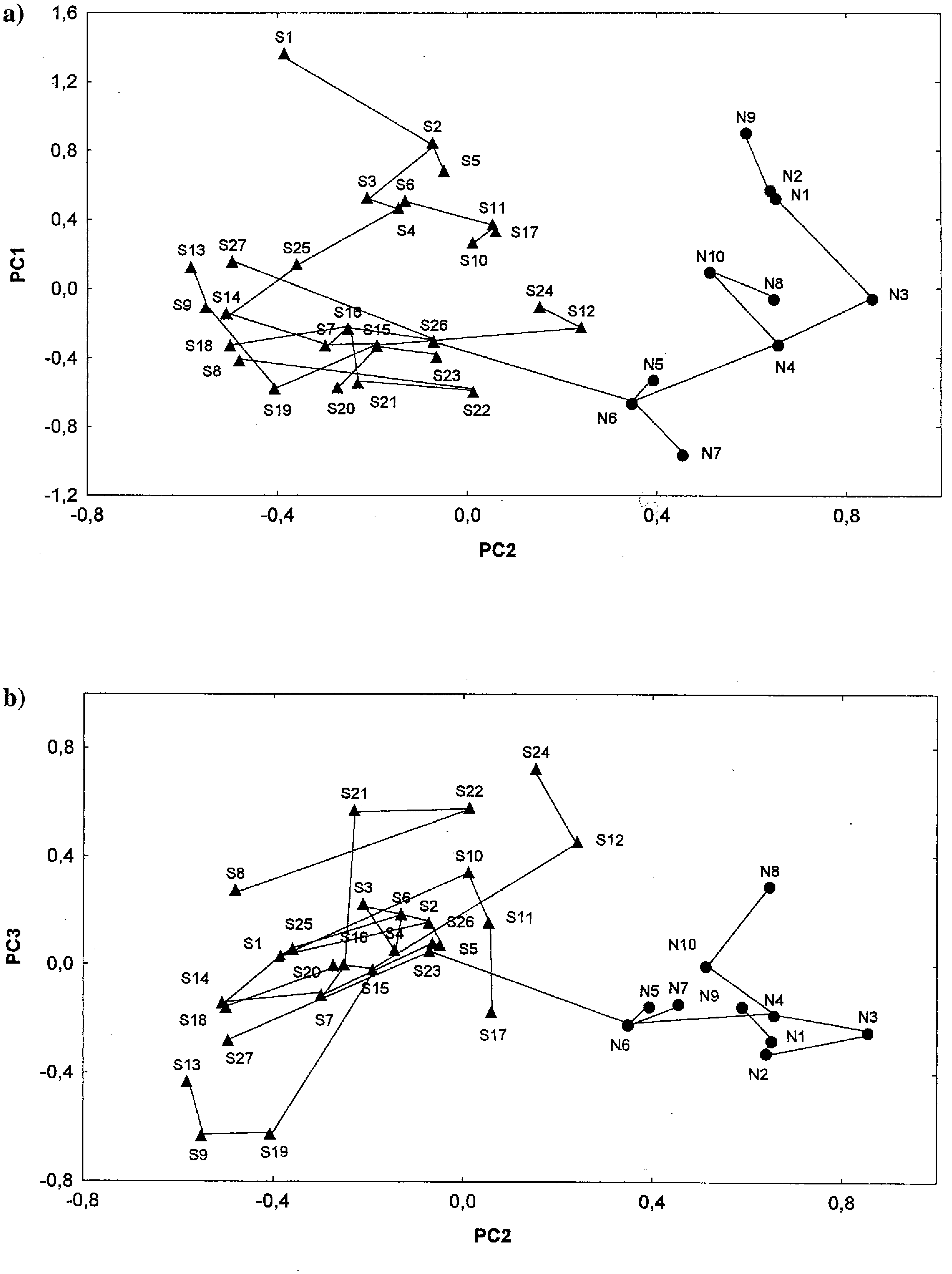

Fig. 2. PCA and minimally connected network of all metric and meristic characters for 27 *A. sturio* (triangles S1-S27) and 10 *A. naccarii* (dots N1-N10). See Table 3 for factor loadings. a) Projection of the specimens onto the first (PC1) and second (PC2) principal components. b) Projection of the specimens onto the second (PC2) and third (PC3) principal components.

Table 3. Factor loadings on the first three components extracted by the PCA of all metric and meristic characters for 27 *A. sturio* and 10 *A. naccarii*.

Character	PC1	PC2	PC3
Fl	-0.530	-0.561	-0.449
Sl	-0.672	-0.418	-0.417
lc	0.764	-0.557	-0.125
prO	0.728	-0.595	-0.012
Oh	0.524	0.166	0.036
poO	0.281	-0.402	-0.476
pD	-0.443	-0.825	-0.178
pP	0.723	-0.569	-0.070
pV	-0.340	-0.866	-0.198
pA	-0.629	-0.597	-0.342
lpcd	-0.347	0.361	0.039
lpc	-0.186	0.744	-0.080
P-V	-0.866	-0.276	-0.217
P-A	-0.907	-0.105	-0.305
V-A	-0.644	0.234	-0.420
lD	-0.137	0.586	-0.365
hD	0.704	0.215	0.312
lPbs	0.385	0.147	-0.325
lP	0.733	-0.159	0.219
lVbs	-0.279	0.148	-0.207
lV	0.739	0.068	0.222
lA	0.243	0.047	-0.525
hA	0.388	0.193	0.294
H	0.071	-0.329	-0.271
h	0.062	-0.214	-0.554
hco	0.492	-0.123	-0.403
hc	0.031	-0.406	-0.520
lam	0.527	0.678	-0.426
laim	0.553	0.649	-0.393
lac	0.438	0.152	-0.610
io	0.739	0.107	-0.476
lasa	0.504	0.391	-0.551
lab	0.592	0.619	-0.288
lb	0.778	0.175	-0.048
s-m	0.811	-0.518	0.016
s-mc	0.823	-0.477	0.021
s-b	0.792	-0.478	0.049
b-mc	0.746	-0.405	-0.034
Du	-0.133	0.238	0.109
Pu	0.330	0.178	0.138
Vu	-0.275	0.187	0.228
Au	0.017	-0.056	0.473
Cu	-0.213	0.205	0.616
Fu	0.244	0.567	0.000
Sp.br.	-0.412	0.936	-0.322
SD	0.363	-0.492	0.001
SL-left	0.105	0.511	-0.285
SL-right	0.249	0.526	-0.198
SV-left	-0.076	-0.125	-0.123
SV-right	-0.051	0.093	-0.046
Variance explained (%)	27.20	19.31	10.08

Table 4. Metric characters. Results of the ANCOVA between 27 *A. sturio* and 10 *A. naccarii* using total length as covariate (only for characters that became significantly different).

Character	F	P
lc	4.958	0.034
prO	7.516	0.011
pV	6.172	0.019
lpc	7.307	0.012
lam	11.340	0.002
laim	9.506	0.005
lab	14.563	0.001
s-m	5.324	0.029
s-mc	4.744	0.038
s-b	10.703	0.003

the specimens from the River Guadalquivir EBD 8173 and EBD 8174 (the only two preserved specimens from Spain determined by them as *A. naccarii*) and EBD 8401 have the typical skin pattern of *A. sturio*. Likewise, the female sturgeon fished out of the Gulf of Cádiz in 1992 (Elvira & Almodóvar 1993), only known by some metric data and colour photographs, also bears the skin pattern of *A. sturio*, and, consequently, our former identification is confirmed.

The number of gill rakers seems to be a good diagnostic character to distinguish *A. sturio* from *A. naccarii*, with no overlap of their ranges found in our samples. This very important character was not used by Garrido-Ramos et al. (1997). All known native sturgeons of Spain were consequently determined as *A. sturio*. The two preserved Spanish sturgeons reported by Garrido-Ramos et al. (1997) as *A. naccarii* (both studied by us) also correspond to *A. sturio*. This conclusion is very significant from the point of view of conservation, since all the efforts must be directed to the only known native sturgeon species *A. sturio*.

Ludwig & Kirschbaum (1998) and Doukakis et al. (2000), who still considered *A. naccarii* as an Adriatic endemism, also discuss the molecular results of Garrido-Ramos et al. (1997). In fact, *A. naccarii* is a Ponto-Caspian species closely related to the Siberian sturgeon *A. baerii* Brandt, 1869 and the Persian sturgeon *A. persicus* Borodin, 1897 (Birstein & DeSalle 1998). Only three Ponto-Caspian sturgeon species are native to the Mediterranean Sea, having their westernmost range at the Adriatic Sea: *A. naccarii*, *A. stellatus* Pallas, 1771 and *Huso huso* (L., 1758). The original occurrence of these species in the Atlantic rivers (i.e. the Guadalquivir) is unlikely from a biogeographical approach.

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