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Major problems concerning the conservation and recovery of the Atlantic sturgeon *Acipenser sturio* L., 1758

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ABSTRACT

Analysis of existing data and information show that the present status of the Atlantic sturgeon *Acipenser sturio* L., 1758, is much more complex than that of any other sturgeon worldwide. The name *A. sturio* includes 9-12 geographically, and probably also reproductively, isolated populations with disrupted gene flow. If so, and if there are both morphological and genome differences among them, then this name is used to designate several distinct species. Restoration programmes for the particular geographic area in which the Atlantic sturgeon has been known must be based on the stocking of offspring of the same genome from ancestors coming from the same geographic area. The stocking of specimens from other geographic areas would be similar to introduction of an exotic species *sensu stricto*, resulting in wide-ranging, unexpected and irreversible consequences. Therefore, the ultimate decision on such stocking has to be preceded by careful and scientifically sound analyses of the intended action. Any final solution to this problem needs close international co-operation and financial support from the countries concerned.

Key words: Distribution, morphology, genome, taxonomy, ecology, recovery.

RESUMEN

Problemas importantes relacionados con la protección y recuperación del esturión atlántico* Acipenser sturio *L., 1758

El análisis de los datos e informaciones existentes muestra que el estado actual del esturión atlántico Acipenser sturio *L., 1758 es mucho más complejo que el de cualquier otra especie de esturión en todo el mundo. El nombre* A. sturio *comprende 9-12 poblaciones geográficamente, y probablemente también reproductivamente, aisladas con una corriente interrumpida de genes. Si es realmente así, y entre estas poblaciones existen diferencias tanto morfológicas como genómicas, este nombre denomina entonces varias especies distintas. Los programas de recuperación para un área geográfica particular en la que* A. sturio *ha sido conocido tienen que estar basados en la repoblación con descendientes con idéntico genoma de ancestros procedentes de la misma región geográfica. La repoblación con ejemplares de una región geográfica diferente significaría la introducción de una especie exótica* sensu stricto*, resultando una ampliación de su rango, con consecuencias imprevistas e irreversibles. Por eso, la decisión final sobre tal repoblación tiene que basarse en un análisis cuidadoso y científicamente sólido de la acción proyectada. Cualquier solución final de este problema exige una estrecha colaboración internacional y también el apoyo económico de los países involucrados.*

Palabras clave: *Distribución, morfología, genoma, taxonomía, ecología, recuperación.*

To my friend, former colleague and co-worker, frequent opponent and sometimes also rival and competitor, Dr. Eugene K. Balon on the occasion of his 70th birthday

INTRODUCTION

"Basic systematic data are important for conservation. Without detailed surveys and accurate taxonomy, it is impossible to identify the various species and evaluate their real conservation status, it is impossible to properly manage their fisheries, it is impossible to establish strategies and it is impossible to set priorities. Without accurate names, it is impossible to list a species as endangered or threatened and to take conservation action" (Kottelat, 1998).

The Atlantic sturgeon belongs on the list of critically endangered fish and is included in the Red Data Book of almost all countries where it was known to occur (e.g. Borodin, Bannikov and Sokolov, 1984; Botev and Peshev, 1985; Anon., 1986; Baruš, 1989; Keith, Allardi and Moutou, 1992; Glowaciński, 1992; Witkowski *et al.,* 1999; Karandinos and Paraschi, 1992), and also in the IUCN (Anon., 1996), CITES (Anon., 1992) and the Bern Convention (Anon., 1979). As reported elsewhere (Holčík *et al.*, 1989), the curve of its catches dramatic decline mirrors the decline of the species population density, which started at the beginning of the 20th century. The curve is both very similar in different countries and also almost perfectly synchronous in neighbouring regions. The main reasons for this rapid decline have been known for a long time, i.e. river regulations and the catch of juveniles (Roule, 1925). Attempts to save this species date back to the 1860s, when Kessler (1864) requested the total ban of its fishery in the Volkhov River "to ensure by this way, more or less the existence of the Atlantic sturgeon in the Gulf of Finland" (Kessler, op. cit., p. 212). Then Kulmatycki (1933) and Berg (1935) requested the conservation of this valuable fish, including a total ban on its fishery in Poland and Russia. However, their attempts were not successful in adjacent countries, and even in Poland and Russia the total ban on the fishery of this species was implemented only in 1952 and 1967, respectively (Dyduch-Falniowska, 1992; Ninua and Tsepkin, 1984). Ironically, the most abundant stocks of the Atlantic sturgeon, found in the North and Baltic Seas, were eradicated first, followed by those inhabiting the southern Mediterranean and Adriatic Seas. That it was the river regulations, along with the plundering fishery aimed at gaining its valuable flesh, and then mainly the caviar, is now generally admitted. It may be documented by the example of the Guadalquivir and Gironde Rivers' sturgeon, which were affected by fishery rather late in comparison with the northern stocks. Unfortunately, the catastrophic decline of the northern Atlantic sturgeon was not a sufficient warning, and the previous mistakes have been repeated. In both rivers, sturgeon was a common species, exhibiting migrations reaching far from the river mouth. In comparison with the northern countries, the demand for sturgeon started later. In the Guadalquivir River, its abundance and regular fishery initiated the establishment of a caviar and flesh factory in 1930 (Elvira, Almodóvar and Lobón-Cerviá, 1991b), and in the Gironde River the caviar industry started in 1920 (Williot *et al.*, 1997). Its existence lasted only a relatively short time: 30 and 50 years, respectively. In addition to fisheries, other factors including dam construction, river regulation, gravel and sand extraction, and pollution contributed to the dramatic decline and then the end of the sturgeon fishery.

Recent attempts to save this valuable species by means of restoration programmes (e.g. Elvira, Almodóvar and Lobón-Cerviá, 1991a, b; Debus, 1996; Sych, 1996; Williot *et* al., 1997) will be difficult, and involve some serious problems, as discussed below, and in addition to those mentioned by Birstein, Betts and DeSalle (1998).

WHAT IS *Acipenser sturio*?

This question forms the first, and also the most important, problem which has to be solved. The complex and situation for both Acipenseridae and the Atlantic sturgeon was tellingly characterised by Kottelat (1997, p. 30): "Due to their large size, museum samples of most species of Acipenseridae are rare. As a result, many species descriptions were based on few specimens only and their variability is not very well known… For various reasons (usually unsuitable concepts and methods), this has resulted in only few data usable in systematic analysis. One of the significant problems… is that authors very rarely compare specimens, but only compare data compiled from a variety of sources, whose consistency can always be doubted." In other words, the first problem is to determine which stock or population may be named as Atlantic sturgeon *Acipenser sturio* L., 1758. This task is rather difficult now, as there are only a few museum specimens and the data on the morphology of *A. sturio* found in various sources of literature are similar or identical, suggesting that they were simply copied from author to author (e.g. Brandt and Ratzeburg, 1833 → Heckel and Kner, 1858 → Siebold, 1863 → Kessler, 1864 → Berg, 1916 → Berg, 1948 → Staff, 1950 → Gąsowska, 1962 → Bryliňska, 1986; Marti, 1939 → Svetovidov, 1964 → Pavlov, 1980; Spillmann, 1961 → Tortonese, 1970 → Billard, 1997). Original data introduced by some authors are scarce, and taken from few specimens; therefore proper statistical analysis is impossible (e.g. Günther, 1870; Ivanović, 1973; Almaça, 1988; Oliva, 1995). According to Linnaeus (1758), the type locality for *A. sturio* are European seas ("... *in mari Europaeo*"). We know, however, that there existed at least 9-12 stocks of sturgeon recorded as *A. sturio,* which are geographically, and thus also reproductively, isolated (figure 1). This suggests the possibility of an allopatric speciation, and thus the existence of several species. This statement is supported by the following facts.

- First of all, it is necessary to know the geographical locations of syntypes. The text of Linnaeus is based on specimens from his own 1746 account and on the accounts of Gronovius and Artedi. One needs to know if he gives locality information in his 1746 account, and what Gronovius and Artedi say. The total locality assemblage is the type locality. If it is not possible to reach a conclusion, the syntypes of *sturio* in the British Museum (Natural History) may be used to identify the particular population, based on the tag description of this (these) specimen(s). If successful, one can designate a lectotype. If not, one should find a specimen suitable as neotype and ask the International Commission of the Zoological Nomeclature to designate this specimen as neotype.
- There are significant morphological differences between various stocks of the Atlantic sturgeon. As reported by Holčík *et al.* (1989) and recently also by Debus (1999), the number of dorsal and lateral scutes in the Baltic stock are significantly lower than in the Atlantic Ocean, the Mediterranean Sea and the Black Sea stocks (table I). On the other hand, the number of branchial spines in sturgeon from the Rioni River (Black Sea) and the Gironde River (Atlantic Ocean) are also different. In these two populations, a Student's *t*-test revealed statistically significant differences (table II). Although the values of the CD test are not statistically significant and show a wide overlapping of data, it need not be controversial in this respect. The European Atlantic sturgeon *A. sturio* and the North American Atlantic sturgeon *Acipenser oxyrinchus* Mitchill, 1815 were considered to be conspecific for 150 years, because of their seeming morphological closeness (Magnin, 1963, 1964). Only recently were they confirmed as a separate species by molecular analysis (Wirgin, Stabile and Waldman, 1997). Also, Almaça (1988) admitted the genetic and phenotypic differentiation between the populations ascending the Guadiana (Cadiz Bay) and the Douro (Bay of Biscay) Rivers.
- Fish frequently show clinal variation in their counts, which is both size and temperature dependent. Larger specimens from northern areas display a higher number of their meristic characters (Holčík and Jedlička, 1994). This has also been shown to be true for *Acipenser baerii* Brandt, 1869 (Ruban 1989, 1997, 1998). However, this association cannot be taken as *a priori,* meaning that such a rule applies for all sturgeon species, and has to be demonstrated (experimentally) case by case. Existing data on the Atlantic sturgeon, although very limited, show that the sturgeon stock from the Baltic Sea and the Atlantic Ocean, which are larger in size, have fewer dorsal and lateral scutes and branchial spines than the Black Sea sturgeon. In other words, the large sturgeon from the northern regions have a lower number of scutes and branchial spines than the small sturgeon from the southern regions. This clearly indicates that the clinal variation does not exist between the northern and southern populations of the Atlantic sturgeon, and that the observed data point to a specific differentiation between these populations.
- Data from other migratory and nonmigratory fish species show the homing or site fidelity of spawning populations. This ability was also postulated for *A. oxyrinchus desotoi* according to both genetic analysis and tagging (Wirgin, Stabile

and Waldman, 1997). Although there is some mixing of *A. sturio* stocks among particular populations inhabiting a region with several neighbouring and even extant tributaries (Castelnaud *et al.*, 1991), the sexually mature fishes spawn in their home river. In this respect *A. sturio* seems to differ from *A. oxyrinchus*, in which spatially restricted straying is limited to one region (Stabile *et al.*, 1996). In other words, stock mixing is possible within one region, but reproductive mixing is highly improbable among geographically isolated stocks. Nevertheless, this cannot be an *a priori* rule but has to be demonstrated on a case-by-case basis.

- It is known that Lake Ladoga (Baltic Sea watershed) was inhabited by a resident, non-anadromous population of sturgeon (Berg, 1948; Kozhin, 1964; Poduschka, 1985). In the southern regions similar populations of this species were not reported, despite the existence of at least one analogous situation in Lake Skadar (Adriatic Sea watershed). This lake was occasionally entered by sturgeon, prior to spawning, but the existence of a resident population was not recorded (Poljakov *et al.*, 1958; Ivanović, 1973).

Table I. Mean number of dorsal (SD) and lateral (SL) scutes in the Atlantic sturgeon from different watersheds (data from Magnin, 1963 and Ninua, 1976; according to Holčík *et al.*, 1989)

Watershed	SD	SL
Baltic Sea	9.6	27.7
Atlantic Ocean	12.7	35.1
Mediterranean Sea	13.0	35.1
Black Sea	13.5	32.0

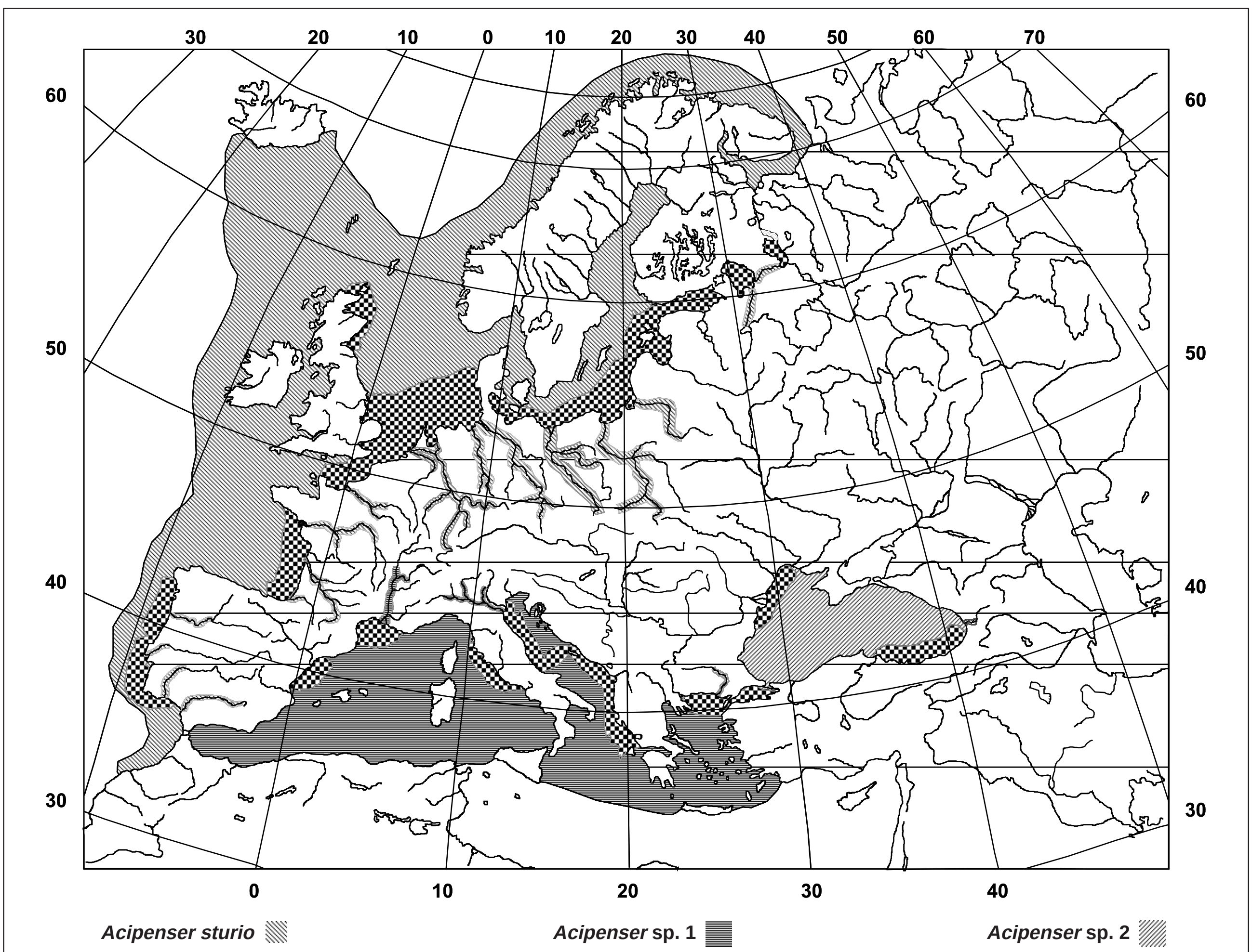

Figure 1. Distribution of *Acipenser sturio* and two supposed undescribed sturgeon species in Europe. Shaded regions denote areas with known local, geographically isolated populations. The draughtboarded drawing indicates the usual distribution of local populations. See text for explanation

Table II. Statistics on two populations of the Atlantic sturgeon. Data for the Rioni River from Ninua (1976) and those for the Gironde River from Magnin (1963). Student's *t*-test and coefficient of difference (CD) tests calculated by Holčík. (Du): number of rays in dorsal fin; (Au): number of rays in anal fin; (SD): number of dorsal scutes; (SL): number of lateral scutes; (SV): number of ventral scutes; (Sp.br.): number of gill rakers. (***): $p < 0.001$

Character	Rioni River (Black Sea)					Gironde River (Atlantic Ocean)					t	CD
	$\bar{x}$	s	$s_{\bar{x}}$	Ranges	n	$\bar{x}$	s	$s_{\bar{x}}$	Ranges	n		
Du	43.00	–	–	39-50	54	–	–	–	–	–	–	–
Au	25.00	–	–	23-28	7	–	–	–	–	–	–	–
SD	13.47	0.64	0.07	11-15	83	12.74	1.24	0.13	9-16	91	4.94***	0.39
SL	31.96	1.37	0.15	28-36	83	35.13	1.91	0.20	31-39	91	12.68***	0.97
SV	10.47	0.55	0.06	9-12	83	11.03	0.95	0.10	9-13	91	4.80***	0.37
Sp.br.	24.87	1.55	0.17	22-29	83	20.19	2.29	0.25	16-26	91	15.48***	1.22

Ironically, the details on the life history of this species of sturgeon are not properly known despite its wide geographical distribution. For instance, it is not known whether this species has spring and winter races, as is known for many sturgeon, especially in the Ponto-Caspian region (Berg 1934). Available data, however, suggest that both a spring and a winter race existed in the Rhine and Vistula Rivers, with the latter entering the river from August to October (Kulmatycki, 1932; Kinzelbach, 1987). The same is probably true for the Tagus and Guadalquivir, where catches of this species are known in late November (Almaça and Elvira, 2000) and in January (Classen, 1944; Holčík *et al.*, 1989). This does not imply that similar races exist(ed) in all populations. Also, the differences in the food quality between the northern and southern populations could affect their specific differences. While the main or preferred food of adult sturgeon from the northern seas are the bottom invertebrates (Mohr, 1952; Magnin, 1963), adult sturgeon from the Black Sea feed predominantly on the pelagic anchovy *Engraulis encrasicolus* (L., 1758) (Marti, 1939; Pavlov *et al.*, 1994). This also points to the different habitats of sturgeon in these regions: while the northern fish are of a benthic form, those from the Black Sea seem to be pelagic.

Generally, the morphological and ecological differences between the Atlantic sturgeon populations are more significant than the differences between *Acipenser gueldenstaedtii* Brandt & Ratzeberg, 1833 and *Acipenser persicus* Borodin, 1897, formerly considered conspecific (Vlasenko, Pavlov and Vasil'ev, 1989).

All of the above data strongly suggest that several species have been confused under the name *A. sturio*. Assuming larger geographical units, there are at least two and perhaps three closely related species isolated both geographically and reproductively (figure 1). The name *A. sturio* could be used for populations occurring in northern seas, and the *terra typica* of this fish could be the Baltic Sea or the North Sea (see note above). The distribution of *A. sturio sensu stricto* probably includes the entire Atlantic coast of Europe. The second presumptive species, for which no formal name is presently available, probably comprises populations from the Mediterranean, Adriatic and Aegean Seas. Eastern populations, especially those inhabiting the eastern part of the Black Sea, probably represent another species which also awaits formal description.

This hypothesis is now supported by the discovery of significant morphological differences between the North Sea sturgeon and the Iberian and Adriatic populations (Elvira and Almodóvar, 2000) and by Groeger and Debus (1999), who found significant differences in some morphometric characters between the sturgeon populations from the Baltic Sea and Atlantic Ocean. The generated polymerase chain reaction (PCR) data from sturgeon caught in the North Sea and the Bay of Biscay (Ludwig and Kirschbaum, 1998), sturgeon taken from the Gironde River and in the North and Baltic Seas (Birstein, Betts and DeSalle, 1998), and also sturgeon from the Baltic and Mediterranean Seas (Birstein and Doukakis, 1999) provide further support for this hypothesis.

The need for a precise revision of *A. sturio* also stems from the controversial paper by Artyukhin and Vecsei (1999). Although the specific distinction of *A. sturio* and *A. oxyrinchus* is now generally accepted (Birstein and Bemis, 1997; Birstein, Bemis and Waldman, 1997; Birstein, Hammer and

DeSalle, 1997), Artyukhin and Vecsei (1999) claim that both species are conspecific, and there are four subspecies within what they call the *A. sturio* complex. Unfortunately, their data lack depth and their discussion lacks critical statistical analysis. These authors also ignore not only the genetic data, but also the existing information on the morphology of non-Baltic populations of *A. sturio.* Moreover, their paper suffers from the crude absence of a clear concept of species and the gross ignorance of basic systematic principles and of the International Code of Zoological Nomenclature. Their "*Acipenser sturio occidentalis* subspecies nova" is therefore a *nomen nudum.* This paper illustrates the need to clarify the systematic status of populations occurring in particular regions, through a critical and competent systematic and taxonomic analysis, with clear principles and species concept (Kottelat, 1997). However, achieving this goal may be almost impossible, as many sturgeon populations are already extinct.

IS IT POSSIBLE TO USE FOREIGN POPULATIONS FOR THE RESTORATION OF THE EXTINCT ONES?

This question is the logical result of the conclusions from the previous section. If a species becomes extinct in some river or basin, it should be restored (the term reintroduction frequently used in conservation –e.g. Birstein, Bemis and Waldman, 1997– is correct only in cases where the first introduction of some species to its original home territory failed; the correct term for the translocation of a species to its native territory, in which it ceased to exist in the past, is restoration or restitution) by the introduction of the same species. However, it has to be proved that the foreign population belongs to the same species. As discussed in the preceding section, the similarities between sturgeon from different geographical areas are not clear. If the Baltic Sea watershed were stocked and then inhabited by sturgeon from the Black Sea, as suggested by the Polish recovery programme (Skóra, 1996; Sych, 1996) there would be a risk of unexpected results from such an introduction. In this case, the Black Sea sturgeon would be an exotic species in the Baltic Sea watershed. It is well known that the introduction of an exotic species is frequently harmful to native fishes and other taxa, through competition for food and space, predation, hybridization, introduction of exotic pathogens, and habitat and water quality alterations (Arthington, 1991; Holčík, 1991). Some of the effects of such introduction are irreversible, and may also have genetic consequences (Philipp, 1991). The question also is whether the introduced exotic species or foreign population survives. Moreover, the introduction of a foreign population may not result in the formation of a reproducing population; stocking of brown trout *Salmo trutta* L., 1758 from one river basin to another was not always successful (Arias, Sánchez and Martínez, 1995; Largiadèr and Scholl, 1995) because the foreign fish were not genetically adapted to the new environment. In Slovakia repeated stocking of both the broodfishes and juveniles from the Váh River into the Orava River did not result in the recovery of *Chondrostoma nasus* (L., 1758) (Bastl and Holčík, 1997). The same is true for the critically endangered huchen *Hucho hucho* (L., 1758), which did not establish self-reproducing populations in some rivers in which it was planted (Holčík, 1997). The juvenile huchen originated from a few broodfish collected in one river, which were used in a single hatchery for artificial reproduction.

AQUACULTURE AND HATCHERY IMPLICATIONS

Experiences with the planting of the aquaculture stocks of various salmonid species, including the attempts to restore the lake trout *Salvelinus namaycush* (Walbaum, 1792) in the Great Lakes, revealed that artificially bred stocks have reduced genetic diversity and their capability to reproduce in the new environment is decreased (Doyle *et al.*, 1991; Evans and Willox, 1991). It has also been found that the hatchery strain typically bears little genetic similarity to the wild population, and the genetic differences between hatchery and wild fish often translate into important differences in physiological, behavioural, and other traits related to fitness (Krueger and May, 1991). In the brown trout a very low number of stocked individuals have been observed, despite the long period of repopulation, and the hatchery-adapted genotypes may not survive or grow well when released into the wild (Arias, Sánchez and Martínez, 1995).

As is well known, the stocking of hatchery-reared juveniles has been used to maintain populations of the most important (from the commercial point of view) species of sturgeon, such as *Huso huso* (L., 1758), *A. gueldenstaedtii* and *Acipenser stellatus* Pallas, 1771 in the former Soviet Union. However, the initial success of the stocking has been replaced by a declining trend. In spite of a substantial increase in the number of the hatchery-produced juveniles during the last 30 years, the stocking of these three species did not affect either the catch or the number of spawners (Khodorevskaya *et al.*, 1997). Dam construction, the decreasing level of the Caspian Sea, poaching, and increasing water pollution are all blamed for this failure. It is likely, however, that the loss of genetic diversity within the decreasing number of spawners used for the artificial propagation is also a potential reason for this failure. The same can possibly explain the collapse of the rearing experiments with *A. sturio* in France (Williot *et al.*, 1997). One must agree, therefore, with Lelek (1996, p. 340) "that the stocking itself brings about no solution to repopulation of vanished species" and with Birstein, Bemis and Waldman (1997, p. 429) that "We must make the case throughout the world that even the very best stocking programs can only provide short-term solutions unless they are coupled to plans for protecting and increasing the levels of natural reproduction." In other words, it is vital to conserve the natural environment and, if disrupted, to help it to recover natural conditions. Shagaeva *et al.* (1993) show that in cases where natural reproduction is facilitated, poor environmental conditions can significantly reduce the survival of developing embryos and juveniles.

Birstein, Betts and DeSalle (1998, p. 97) offer the following warning: "A careful genetic evaluation of each captured putative *A. sturio* individual which potentially can be used for breeding in restoration projects is recommended"; i.e. each action ignoring these recommendations and warnings may result in quite the opposite effect. Instead of the conservation and rescue of the populations and/or species under consideration, their extinction may be sealed.

CONCLUSIONS

The situation of the European Atlantic sturgeon is much more complicated than in other species of sturgeons. It can be summarised as follows.

- The scientific name *Acipenser sturio* L., 1758 covers 9-12 geographically and apparently also reproductively isolated populations. If this is confirmed, then this name is currently used for several distinct species. The situation can only be clarified through critical research.
- The restoration programmes for particular geographic areas in which the Atlantic sturgeon has been known to thrive in the past must be based on the stocking of offspring of the same genetic make-up as the previous inhabitants.
- The stocking of specimens from other geographic areas would be comparable to introduction of an exotic species bringing with it wide-ranging, unexpected and irreversible consequences. This should absolutely be avoided, unless preceded by the careful and scientifically sound analyses of the intended action. Considering that the stocked species will potentially disperse into the waters of other countries, international co-operation is needed to avoid imperiling conservation or restoration efforts elsewhere.
- The final solution requires close international co-operation, with financial support from the countries involved.

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