Status and Management of Eurasian Sturgeon: An Overview

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I. Conservation and Broodstock Management				

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key words: landing, decline, managing, damming, regulation, recovery measures, stocking, perspectives

Abstract

This paper is an attempt to delineate the causes for the dramatic decline of the most part of European sturgeon species and the recovery measures taken. Overfishing, damming, pollution, poaching, water pumping, and dredging are the main quoted causes for the decline of sturgeon populations. 2 to 6 causes are cited simultaneously. Ranking the causes is mostly impossible. Various measures were taken to regulate the fisheries; among them were size limits, restricted catching periods, quotas, no measures at all, and restricted catching areas which accounted for 50%, 50%, 21%, 21% and 14%, respectively. Efficiency of police control, fines, fish-passes, and stocking are reported. Some explanation to apparent contradictions between biological knowledge and sturgeon status are given. There are suggestions in: trade control, *ex situ* conservation, fisheries' biology and/or population management, and the increasing relative weight of sturgeon fisheries.

1. Introduction

Sturgeon species are among the most ancient fish still present on earth, their presence is confirmed from at least 200 MYBC (BEMIS *et al.*, 1997). There are some 25 species spread over the Northern Hemisphere, two third of the species inhabiting Eurasia. The Ponto-Caspian Basin represented up to recent period as much as 90% of the sturgeon world landings. Nowadays, many fisheries completely collapsed, and the respective species or populations are either becoming endangered or extinct (BIRSTEIN *et al.*, 1997). These dramatic declines occurred while these populations were presumably managed and protected by fishery regulation. It is becoming clear that the measures developed to maintain, restore, and

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safeguard these populations did not reach their goal. In other words, the currently used biological and regulatory tools were ineffective to maintain sustainable sturgeon fisheries. Therefore, there should be some other explanations to the decline of sturgeon population that might be out of the sphere of fisheries *stricto sensu*. The main objectives of this synthesis are i) to update most representative stock's abundance patterns through landings, ii) to synthesize the different reasons for the changes, iii) to give a panorama of the main management actions that were used, iv) to discuss the recovery measures, and v) to suggest some lines that might potentially prevent a continuous damage of sturgeon species.

2. Eurasian Species

There are 17 Eurasian species of the Acipenseridae and one of the Polyodontidae (BIRSTEIN *et al*. (1997) (Table 1). According to the classification of BEMIS and KYNARD (1997), eight are potamodromous, that is they spend all their life span in freshwater, two are freshwater amphydromous with some uncertainty, and ten are classified as anadromous as they spend a part of their ongrowing phase in more or less saline water. The anadromous group contains 9 species exhibiting a large range of salinity tolerance. Five species spent their marine ecophase in maximum 16–18‰ salinity waters. Four species are able to support high salinity waters, and one out of the four, *Acipenser sturio*, is represented by populations adapted to very different salinities. A landlocked population was known in freshwater Lado-

Table 1. Eurasian sturgeon species, names (BIRSTEIN *et al*., 1997b), life history pattern (BEMIS and KYNARD, 1997), and maximum salinity tolerance during life span.

Latin name	English name	Life history pattern	Salinity[1] Max (‰)
Acipenser sturio	Atlantic sturgeon	Anadromous	0–35[(3)]
Acipenser naccarii	Adriatic sturgeon	Anadromous	33–37 %
Huso huso	Beluga	Anadromous	12–18[(4)]
Acipenser ruthenus	Sterlet	Potamodromous	0
Acipenser stellatus	Stellate sturgeon	Anadromous	12–18[(4)]
Acipenser gueldenstaedti	Russian sturgeon	Anadromous	12–18[(4)]
Acipenser nudiventris	Ship sturgeon	Anadromous	12–18[(4)]
Acipenser persicus	Persian sturgeon	Anadromous	12–18[(4)]
Psedoscaphirhynchus kaufmanni	Big Amudarya shovelnose	Potamodromous	0
Psedoscaphirhynchus hermanni	Little Amudarya shovelnose	Potamodromous	0
Psedoscaphirhynchus fedtschenkoi	Syrdarya shovelnose	Potamodromous	0
Acipenser baeri	Siberian sturgeon	Potamodromous	0
Huso dauricus	Kaluga	Anadromous	12–16[(5)]
Acipenser schrencki	Amur sturgeon	Potamodromous	0
Acipenser sinensis	Chinese sturgeon	Anadromous	34[(6)]
Acipenser dabryanus	Dabry's sturgeon	FWA[2]	0
Acipenser mikadoi	Sakhalin sturgeon	Anadromous	34[(7)]
Psephurus gladius	Chinese paddlefish	FWA[2]	0

(1) Salinity are from HEDGPETH, 1966 and IVANOV, 1972 otherwise mentioned
(2) Freshwater amphydromous (BEMIS and KYNARD, 1997)
(3) From Ladoga Lake to Atlantic Ocean
(4) Depending on Seas (Caspian and Azov, and Black Seas respectively)
(5) KRYKHTIN and SVIRSKII, 1997
(6) WEI *et al*., 1997
(7) BIRSTEIN and BEMIS, 1997

ga Lake (Barannikova and Holcik, 2000), and important anadromous populations were present in very low salinity water in Baltic Sea (5–8‰) (Mamcarz, 2000), medium salinity in Black Sea (18–20‰) (Ninua, 1976; Holcik *et al.*, 1989), and ocean salinity for population inhabiting the Atlantic coast (Magnin, 1962; Trouvery *et al.*, 1984). There are other examples of sturgeon diversity. The Siberian sturgeon, *Acipenser baeri*, having a wide distribution from Siberian rivers to Baikal Lake, was proposed to be divided into three subspecies (Ruban, 1997). The second example is common to some species (e.g. *Huso huso* and *Acipenser gueldenstaedti*). They exhibit a wide anadromous migration period with two relative peaks in spring and winter leading to distinguish two forms (Pirigovskii *et al.*, 1989; Vlasenko *et al.*, 1989). In both latter cases, there is no genetic support for these classifications (Birstein and Bemis, 1997). Non surprisingly, there are still some taxonomic – geographical controversies: i) the geographical distribution of *Acipenser naccarii* (Garrido-Ramos *et al.*, 1997; Hernando *et al.*, 1999; Almodovar *et al.*, 2000) could have been larger than previously assumed, ii) the speciation of *A. sturio*, which might correspond to different groups (Birstein et al, 1998; Holcik, 2000), iii) the genera distinction *Huso – Acipenser* (Birstein *et al.*, 1997), and iv) the species inhabiting the Pearl River (Wei *et al.*, 1997).

3. Landings' Changes and Related Context

Some significant documented examples are reported from Western Europe to eastern Asia. The Atlantic sturgeon (*Acipenser sturio* L., 1758) was likely one of most widely spread sturgeon species. Its primary geographical distribution was from the Baltic Sea to the North Sea, British Islands, English channel, Atlantic cost of France, Iberian peninsula, Mediterranean (France and Italy), Adriatic Sea (Italy), Greece and Black Sea (Magnin, 1962; Holcik *et al.*, 1989; Economidis *et al.*, 2000). The sturgeon population of the Vistula River declined rapidly at the turn of the 19th century following overfishing in the previous period (Mamcarz, 2000). In most parts of Germany and the Netherlands as well, the catches stopped by 1915 with the exception of River Eider (Fig. 1a) of which the last noticeable records occurred in the early 1950s. This river was dammed at Nordfeldt in 1936, and thus blocked upstream migration (Kirschbaum and Gessner, 2000). In France, landings went to zero in the 1970s (Fig. 1b) after a known maximum in the early 1950s. No former data are available, and there are suggestions that catches already dropped from the 1920s onwards (Trouvery *et al.*, 1984). The relatively low level in 1945 is most probably due to World War II. Total protective measure in France was promulgated in 1982. In both France and Germany, size limit and associated zones, periods, and permitted catching methods changed a lot during the exploitation period (Trouvery *et al.*, 1984; Kirschbaum and Gessner, 2000). In addition to these changing regulations, overfishing is the most likely primary reason for the decline. Damming in Germany reinforced this decreasing trend, and pollution is suspected to be an additional reason in France (Williot *et al.*, 1997). The main river where this species inhabited in Spain was the Guadalquivir with known data shown in Fig. 1c. Landings considerably decreased from the early 1960s onwards. A dam was constructed in 1934 some km upstream to Seville, and 20 years later catches dropped definitely under 100 specimen per year.

The presence of this species in the Rioni River in Georgia and adjacent Black Sea is becoming uncertain. Therefore, with the exception of the Gironde-Garonne-Dordogne Basin in France and may be, the Rioni River, it seems likely that the species has been extirpated from other European watersheds. The *Acipenser sturio*'s last known records are given in Table 2. They are distributed among one century, and since 1970, southern river drainage were the last basins where the species inhabited. It may be suggested that the Gironde-Garonne-Dordogne basin in France correspond to the less anthropised river drainage and/or

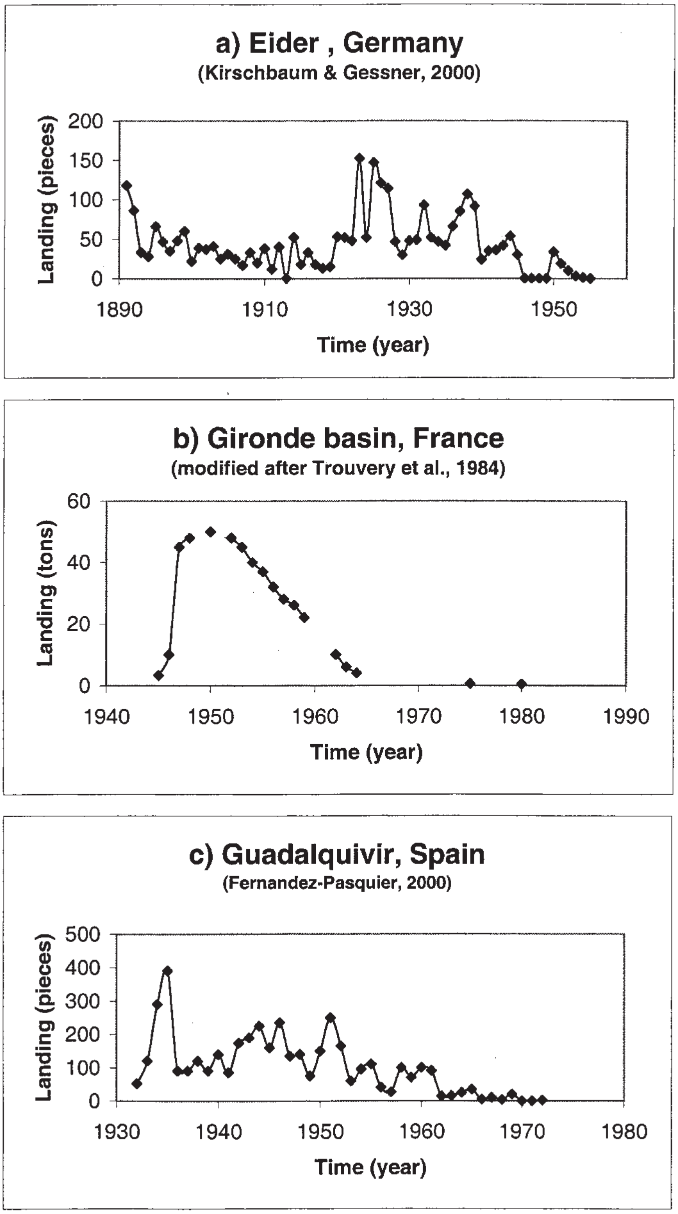

Figure 1. Landings of Atlantic sturgeon (*Acipenser sturio*) in: a) Eider River (Germany), b) Gironde basin (France), and c) Guadalquivir (Spain).

Table 2. Last records for *Acipenser sturio* in Europe

River drainage (Country)	Date	Sources
Ladoga Lake (RU)	1984	Barannikova and Holcik, 2000
Vistula (POL)	Mid 1960s	Mamcraz, 2000
Oder (POL-D)	1952	Gessner and Bartel, 2000
Eider (D)	1969	Kirschbaum and Gessner, 2000
Elbe (D)	1951	Debus, 1995
Weser (D)	1938	Debus, 1995
Ems (D)	1929	Debuss, 1995
Rhine (D-NL)	1942	Kinzelbach, 1997
Seine (F)	1917	Magnin in Allardi and Keith, 1991
Loire (F)	≥1897	Gervais in Allardi and Keith, 1991
Garonne-Dordogne-Gironde (F)	Still present	
Douro (P)	1984	Almaça and Elvira, 2000
Guadiana (P)	Early 1980s	Almaça and Elvira, 2000
Guadalquivir (SP)	1992	Almaça and Elvira, 2000
Ebro (SP)	1970	Almaça and Elvira, 2000
Rhone (F)	1955	Kiener in Allardi and Keith, 1991
Evros (GR)	1975	Georgacas in Economidis *et al.*, 2000
Danube (R)	Doubtful in 1991	Bacalbaça, 1991
Rioni (Georgia)	Still present (?)	

the most suitable biotope of this species as northern and southern populations were extirpated. In the Po River, commercial exploitation of the Adriatic sturgeon, *Acipenser naccarii*, stopped in 1950. The two other species that inhabited this river drainage, *Acipenser sturio* and *Huso huso*, have been extirpated, and the non-disappearance of the Adriatic sturgeon is most likely due to one person who caught some individuals from the wild and kept care of them in farmed conditions.

The next important basin for sturgeon is the Danube where six species were simultaneously present: these are *Acipenser nudiventris*, *Acipenser sturio*, *Acipenser ruthenus*, *Huso huso*, *Acipenser gueldenstaedti* and *Acipenser stellatus*, Most likely, the two former species have been extirpated (Bacalbasa-Dobrovici, 1991). *Acipenser ruthenus*, the sterlet, is a potamodromous species that has been affected by the increasing pollution in the 1950s and 1960s as illustrated by Fig. 2a for the Hungarian part of the Danube. It seems that the population is now recovering. A recreative fishery exploits this population. The three last aforementioned species are anadromous widely spread in Ponto-Caspian basin. The known Yugoslavian situation is described in Fig. 2b. Iron Gates I, constructed in 1969, blocks upstream migration for those species. Landings then increased in the next 15 years due to the high level of catches of fish concentrated downstream to the dam. All populations were affected in such a way that landings decreased significantly after the second Iron Gate dam. The pattern of landings in the Romanian part of the Danube exhibits also a dramatic decrease in sturgeon landings (Fig. 2c). In addition to the negative effects of the above-mentioned dams, overfishing and poaching are the probable reasons for the decline of sturgeon landings as real landings were assessed to be three times as much as those officially declared (Méro, 1998).

The sturgeon landings are also dramatically decreasing in the Azov Sea (Fig. 3). Dams were constructed on both rivers flowing into Azov Sea, at Tsimlyansk (in 1952) across the Don River and at Fedorovsk (in 1967) and Krasnodar (in 1973) across the Kuban River respectively. Since then, more than 90% of sturgeon resources were maintained thanks to stocking fingerlings. Landings were somewhat stabilised during 20 years (1975–1995) around 800 to 1000 tons per year. However, during this period, deep changes occurred.

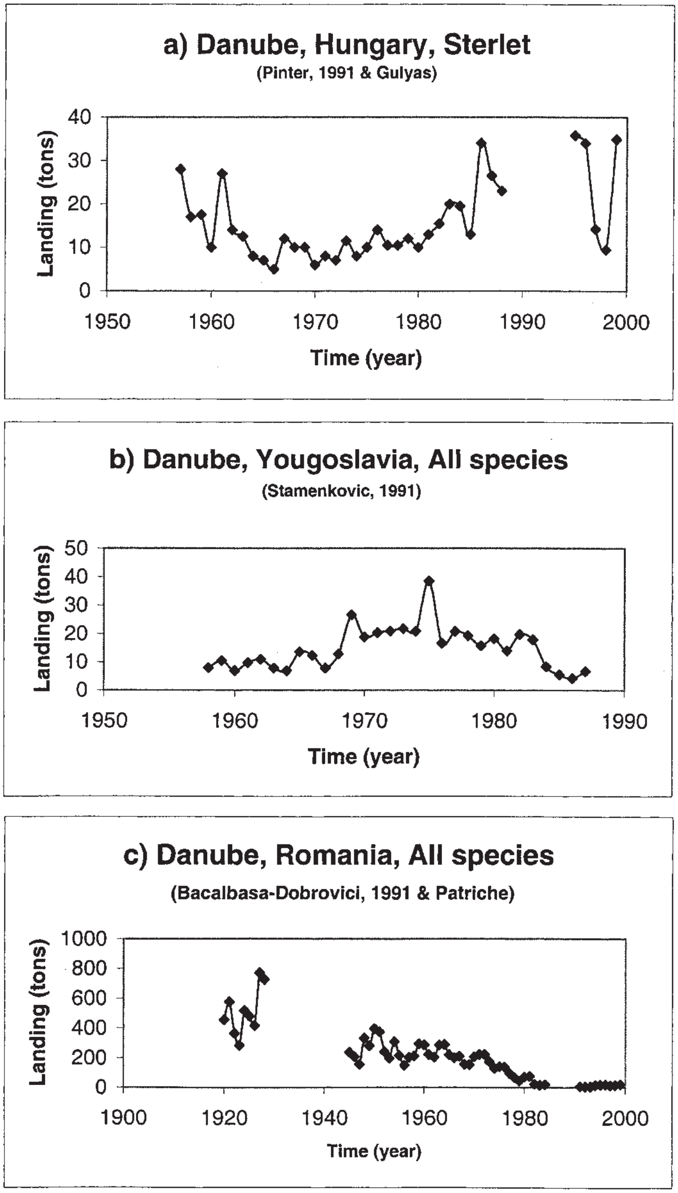

Figure 2. Landings of sturgeon in Danube River: a) Sterlet (*Acipenser ruthenus*) in Hungary, b) all sturgeon species in Yugoslavia, and c) all sturgeon species in Romania. Data from literature are completed by one co-author (Fig. 2a, c)

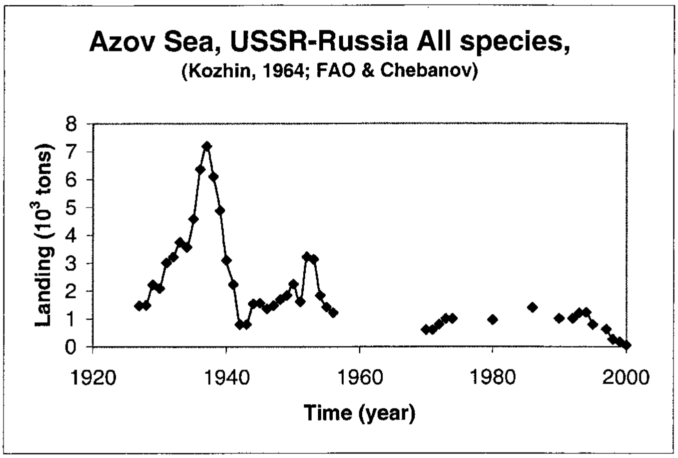

Figure 3. Landings of all sturgeon species in Azov Sea by the former USSR and then Russia. Data from literature are completed by one co-author

There is no more sturgeon in the Don River region and both the hydrology and the sedimentation at the Kuban mouth were deeply modified. This induced changes in sturgeon behaviour. Landings dropped again from the beginning of the 1990s due to a tremendous poaching on sea. Reported gonadic abnormalities (MOISEEVA *et al.*, 1997) suggests a deterioration of the wild.

The quantitatively most productive sturgeon area was the Caspian Sea where two states were previously involved: the former USSR and Iran. Now, Azerbaijan, Kazakhstan, and Turkmenistan got independence. Landings from the former USSR and later Russia are shown in Fig. 4a. Catches were limited to rivers due to the soviet banning of sturgeon sea-fishing in 1962 (SHUBINA, 1975). From World War II on, landings increased until 1977 though the Volga River was dammed for the first time in 1958 at Volgograd and latter upstream at Saratov and Kuybyshev. Consequently, catches started to decrease 20 years after the construction of the first dam, though Volgograd and Saratov dams were equipped with elevators. The reason for this constant decline from the late 1970s onwards is the detrimental effect of poor water quality on survival of juveniles detected in the early 1980s (GERASKIN, 1995). The deleterious effects of pollutants, in Volga and Caspian Sea as well, were lateron extensively described and/or highlighted in eggs, larvae, and adult fish (ROMANOV and ALTUF'EV, 1991; ROMANOV and SHEVELEVA, 1993; SHAGAEVA *et al.*, 1993; VESHCHEV, 1995; KHODOREVSKAYA and NOVIKOVA, 1995; AKIMOVA and RUBAN, 1996) and are now recognised as a major threat (IVANOV, 2000). Since the collapse of the former USSR, poaching amplified the decline of sturgeon populations, it was assessed to be as much important as official landings in the early 1990s (V. P. IVANOV, pers. com.). This analysis involving pollution as a major threat in Volga River is reinforced by the figure from Kazakhstan concerning the Ural River (Fig. 4b). The pattern of decline in sturgeon catches is very similar to that of Russia mentioned above though there is no dam across the Ural River. Pollution of the Northern Caspian Sea and adjacent land and rivers (Volga and Ural) is the most likely responsible for that dramatic situation, petrol and gas industry being an important source of disturbances (GIROUX, 1997) beside biocides from agriculture and many other xenobiontes (LUK'YANENKO *et al.*, 1999; IVANOV *et al.*, 1999).

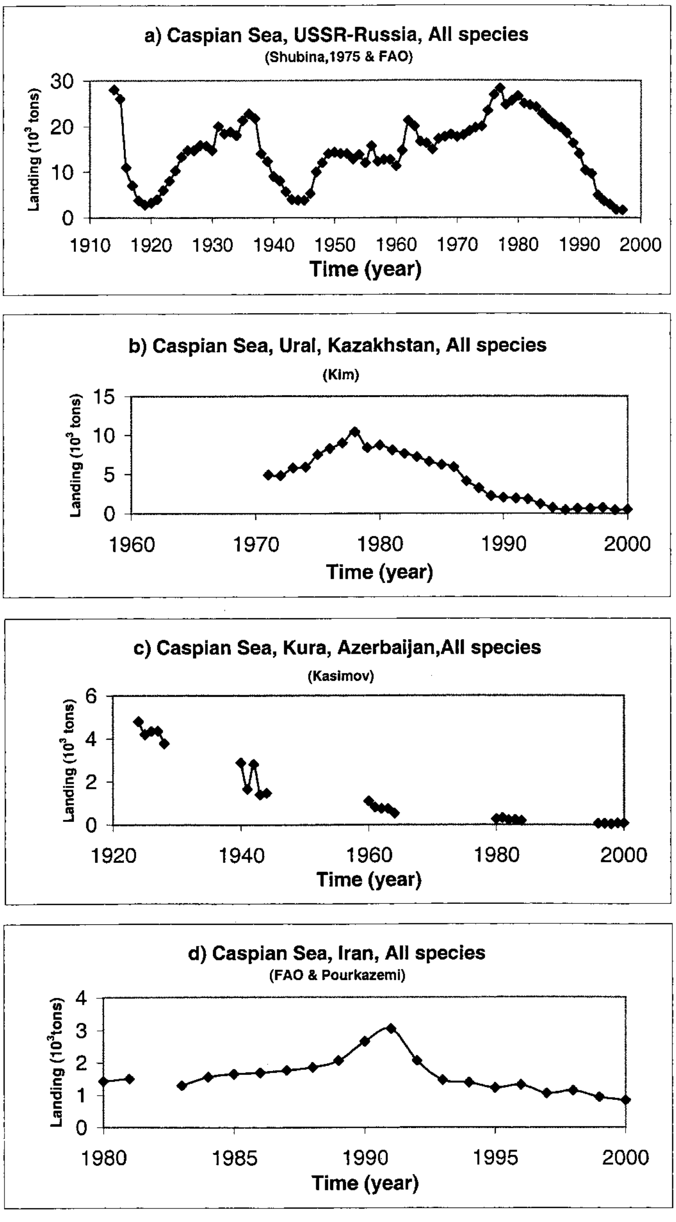

Figure 4. Landings of all sturgeon species in Caspian basin: a) Former USSR and then Russia (in Volga from 1962 onwards), b) all sturgeon species in Ural River (Kazakhstan), c) all sturgeon species in Kura River, (Azerbaijan), and d) all sturgeon species in Iran. Data come from one co-author (Fig. 4b, c) or completed those from literature (Fig. 4d)

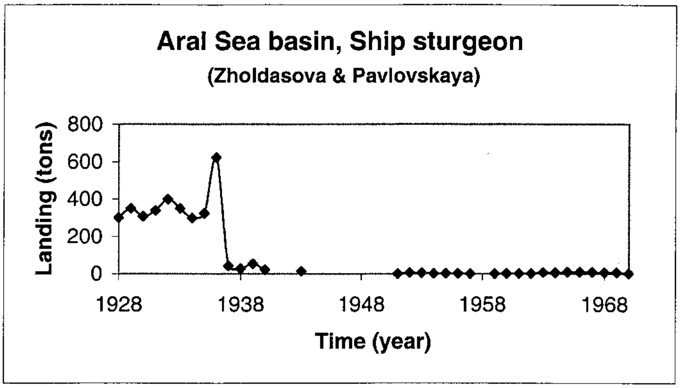

Figure 5. Landings of ship sturgeon (*Acipenser nudiventris*) in Aral Sea basin. Data are from two co-authors

Azerbaijan, with the Kura River, has one of the main river systems of the Caspian Sea. At the beginning of 20th century, this region accounted for more than one fourth of the soviet landings versus 1% in the 1970s (CARRÉ, 1978). This decreasing tendency, illustrated by Fig. 4c, is due to the negative consequences of the building of Minguechaur dam in the early 1960s across the Kura, pollution of nearby Caspian petrol industry, and overfishing. Changes in fishery regulation of former Soviet Union, which banned marine catches to better control sturgeon fisheries, may also have participated in the decline. Iranian landings also exhibit a recent continuous decrease (Fig. 4d). Signs of overexploitation are reported with a decreasing mean length of both sexes of stellate sturgeon *Acipenser stellatus* (MOGHIM and NIELSON, 1999). *Acipenser persicus* is becoming the most important commercial species. In contrast to former USSR, Iranian catching areas are located along the seashore for years.

Aral Sea sturgeon fisheries mainly based on ship sturgeon (*Acipenser nudiventris*) ceased shortly after the introduction of the stellate sturgeon housing the parasite *Nitzschia sturionis* that totally disseminated the ship sturgeon (ZHOLDASOVA, 1997) (Fig. 5). The other sturgeon species endemic to the Syr Darya and Amu Darya rivers, the three shovelonoses (*Pseudoscaphirhynchus kaufmanni, Pseudoscaphirhynchus hermanni* and *Pseudoscaphirhynchus fedtschenkoi*) are extinct or on the verge of extinction due to water pumping and pollution from biocides used in agriculture (ZHOLDASOVA, 1997).

Siberian rivers also exhibited a decrease in sturgeon landings (Fig. 6a). Overfishing, damming in the early 1950s and lateron pollution are responsible for that situation. Abnormalities of the reproductive system (deformation and degeneration of oocytes, amitosis, inclusions in gelatinous membrane, disturbance in nuclear membrane, delamination of yolk membranes, etc.) of Siberian sturgeon have been extensively described (AKIMOVA and RUBAN, 1993; AKIMOVA *et al.*, 1995; RUBAN and AKIMOVA, 2001). There are even data that show detrimental impact on repeated spawners (AKIMOVA and RUBAN, 1995). Landings became negligible from the early 1980s onward. Further in the East, the last important sturgeon exploitation occurred in the Amur River the Chinese part of which is shown Fig. 6b. Two sturgeon species are fished, the kaluga (*Huso dauricus*) and the Amur sturgeon (*Acipenser schrencki*). There is no doubt that the landings will soon decrease, as there is an intensive poaching and overfishing going on as landings in 1993 were four times as much as official records (KRYKHTIN and SVIRSKII, 1997). In the Yangtze River, the Chinese sturgeon (*Acipenser sinensis*) has been exploited till its ban in 1982 following the building of the

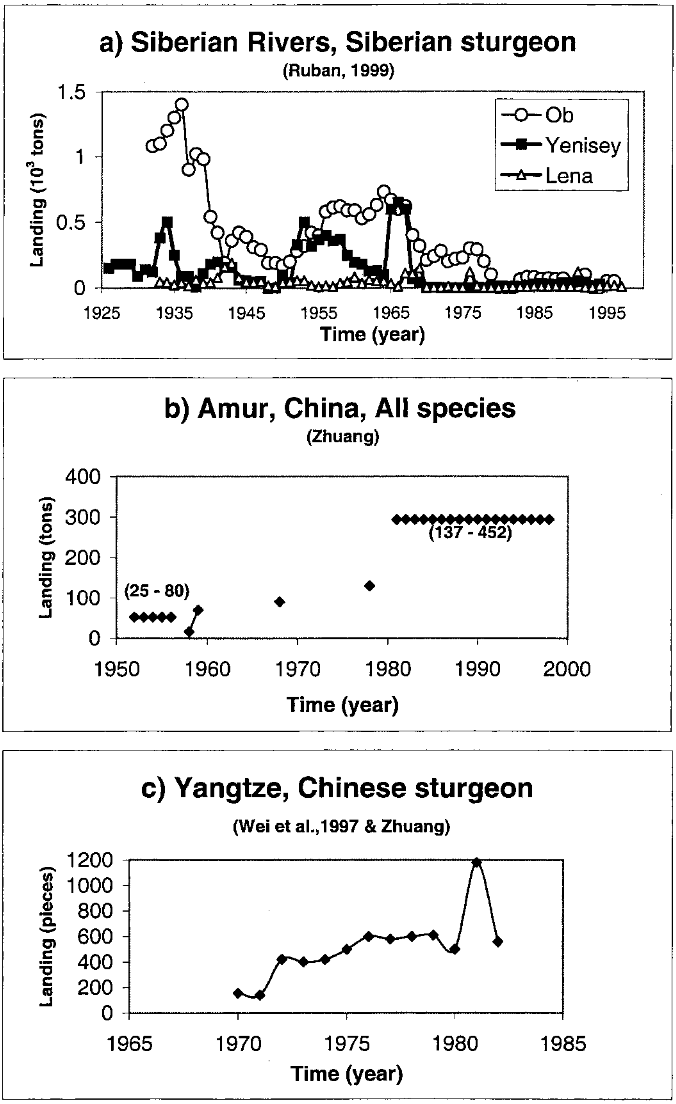

Figure 6. Landings of sturgeon in Siberian waters and China: a) Siberian sturgeon (*Acipenser baeri*) in Siberian rivers, b) all sturgeon species (kaluga, *Huso dauricus*, and Amur sturgeon, *Acipenser schrencki*) in chinese part of Amur River, and c) Chinese sturgeon (*Acipenser sinensis*) in Yangtze River untill total ban in 1982. Data are from one co-author (Fig. 6b) or completed those from literature (Fig. 6c)

Gezhouba dam in 1981. That led to increased landings in 1981/82 (Fig. 6c) due to the concentration of fish below the dam. Catches ranged from 400 to 500 pieces a year in the 1970s (DENG *et al.*, 1991) (Fig. 6c). The two other species inhabiting this river drainage, the dadry's sturgeon, *Acipenser dabryanus*, and the Chinese paddlefish, *Psephurus gladius* are becoming very rare (WEI *et al.*, 1997; ZHUANG *et al.*, 1997). Status of sturgeon population was more dramatic in Pearl River (WEI *et al.*, 1997), and the presence of sturgeon is becoming doubful.

Even in the mid 1990's, two species were extinct, three were critically endangered, nine were endangered, and four were vulnerable (BIRSTEIN *et al.*, 1997a). The present overview shows that the status of most of remnant populations has been deteriorating with the exception of sterlet in central part of Danube. This trend is well illustrated by the Romanian part of Danube where the population of the most abundant sturgeon species (*A. stellatus*) suddenly dropped down again in 1999 (CEAPA *et al.*, in press). In addition, the geographic distribution of the remaining populations is extremely reduced and/or fragmented which contributes to increase vulnerability of these populations. One of them, the beluga stock in Volga is totally supported by stocking for years (BARANNIKOVA, 1987) due to the inability for the species to reach its spawning grounds that are far upstream the Volga and some of its tributaries, namely the Kama River.

4. Management of Fisheries

Facing this panorama, we have been tentatively exploring how these fisheries were managed. For that purpose, a mail survey was conducted by sending to all co-authors a questionnaire of which the main items are reported (Table 3). Authors were requested to give any additional information when necessary. All items were not regularly documented. The first question we were interested in was to present an overview on the reasons that may explain the changes observed in sturgeon landings.

Table 3. Items of the questionnaire related to the management of Eurasian sturgeon Populations

Main item	Sub item
Current management issues facing stocks	
Status of the population	Commercially exploited, sport fishing, protected, endangered …
Reason for depletion	Overfishing, Dredging, Damming, Channelization, Water pumping, Pollution
Fisheries regulation	Quota, Fishing period, Size of fish, Number of licences, Fishing area
Biological and ecological knowledge	
Management of fisheries	Alarm signals, Training of fisheries officers, policy control, fines
Relative weight of fisheries	Ignored, Listened to, Taken into account, Not taken into account
Current management activities or plan to restore and/or maintain stocks	
Habitat improvement	Fish pass (elevators), Spawning grounds, De-pollution
Stocking activities	Origin of breeders, Genetically organised breeding, yearly range of stocking fish, size, efficiency of the stocking
Biology of conservation	Confined stock, Cells conservation, Related-reproduction biology
Co-operation programme	National and/or International level

5. Reasons for Depletion

From 16 river drainage, the main quoted reasons for the decline are in decreasing order: Overfishing (75%), pollution (75%), damming (69%), poaching (56%), water pumping (37%), dredging (31%), channelization (12%), fisheries organisation (12%), sea level (12%), quality of marine nurseries (6%), industrial development (6%), alien species (with parasite) (6%,) establishment of sand bar at river mouth modifying the behaviour of fish (6%), and negative consequences from other countries (6%). Moreover, four reasons (4.1 ± 1.2; mean $\pm$ sd) were quoted to be simultaneously responsible for the deterioration of the status of sturgeon population. When asking as to whether it is possible to rank the causes of decline mentioned above, we got eight replies: three were doubtful, three were negative, and only two were affirmative.

Nevertheless, there are some examples of ranking in the literature that resulted from a posteriori analysis. The extirpation of *A. sturio* from the Vistula River (Poland) is due to: 1) long-term overexploitation, 2) water pumping, 3) hydraulic engineering (stream regulations, damming and harbours construction), and 4) pollution by industry and agriculture (MAMCARZ, 2000). ELVIRA *et al*. (1991) stated that the decline of *A. sturio* in Guadalquivir River (Spain) was due to: 1) damming, 2) overfishing, 3) loss of spawning grounds, and 4) pollution due to industry and urban wastes. RUBAN and AKIMOVA (2001) listed the following causes for the decline of *A. baeri* in the Ob River (Russia): 1) overfishing, 2) hydro-electric dams, 3) heavy pollution, 4) destruction of spawning grounds, and 5) illegal catches. Damming and overfishing are at the top of every list. Difficulties in ranking the reasons for depletion of sturgeon population may be partially illustrated by some examples. Detrimental effect of heavy metal was recently suspected in *A. sturio* in the Gironde River (France) (WILLIOT *et al*., 1997), and the impact on sturgeon population of the so-called "Caspian Sea Problem" (MICKLIN, 1972) due to the changes in sea level remain to be quantified. Moreover stocks, faced with natural and/or anthropogenic changes of environmental factors, e.g. flow rate, temperature regime, and water level, show changes in the survival rate and therefore recruitment fluctuates.

Sometimes adaptations are unexpected. Two examples are reported in Volga River (KHODOREVSKAYA *et al*., 1997). Survival of juveniles *H. huso* is lower than in the past because they spent less time in freshwater and reach sea-water with smaller weight. Similarly, as the juveniles of *A. gueldenstaedti* are less tolerant to higher salinity, their survival decreased when the Caspian Sea level was at the lowest level in the 70s. The regulation of Kuban River introduced deep changes in the spawning season of *A. stellatus* sturgeon. Another change is given by ROCHARD and JATTEAU (1991) who reported a faster growth of juveniles of *A. sturio* in Gironde basin (France) than that mentioned in the 1950s. This may reflect a density-dependant phenomenon due to the dramatic decrease of the corresponding population. Then, consequences of anthropgenic activity might be unexpected and/or difficult to quantify.

6. Damming

Dams are suspected to be one of the primary reasons for the decline of sturgeon stocks and most of the rivers inhabited by sturgeon were dammed (Table 4). Thus, a limitation to the migratory behaviour of sturgeon was introduced, blocking the free access to many of the spawning grounds. The dams also modified the hydrology of the rivers. Some rivers were dammed a long time ago, from the 18^{th} to the early 20^{th} century (Poland, Germany, France, and Spain). Fifty percent of the dams were constructed in the period of 1960–1980. Two dams are still uncompleted, the Three Gorges across the Yangtze River and the dam at Ioumagouzinsk across the Belaia River, a tributary of the Kama River flowing into the Volga River. Moreover, a relationship appeared between changes in sturgeon landings over time

Table 4. Daming characteristics: Country, river drainage and working year

Country	River and tributaries	Damming "name"	Damming year	Source
Poland	Vistula	dams and weirs	18th	GESSNER and BARTEL, 2000
Germany	Eider	Nordfeldt	1936	KIRSCHBAUM and GESSNER, 2000
	Elbe	Geesthacht	1959	LOZAN *et al.*, 1996
	Oder	Chanelization and weirs	18th	GESSNER and BARTEL, 2000
	Weser	Dams and weirs	19th	NOLTE, 1976
France	Garonne	Beauregard	1846	TROUVERY *et al.*, 1984
		Malause	1968	TROUVERY *et al.*, 1984
	Dordogne	Bergerac	1851	TROUVERY *et al.*, 1984
Spain	Guadalquivir	Alcala del Rio (1)	1932	FERNANDEZ-PASQUIER, 2000
Portugal	Douro	Carrapatelo	1971	ALMAÇA and ELVIRA, 2000
		Règua	1973	ALMAÇA and ELVIRA, 2000
		Valeira	1976	ALMAÇA and ELVIRA, 2000
		Pocinho	1983	ALMAÇA and ELVIRA, 2000
Italy	Pô	Isola Serafini	1960	ARLATI
		Casale Monferato	1874	ARLATI
	Adda	Maleo	1980	ARLATI
	Ticino	Panperduto-S.L.	1884	ARLATI
	Oglio	Isola Dovarese Cr	1980	ARLATI
	Mincio	Salionze	1920	ARLATI
Hungary	Danube	Gabcikovo	1992	GULYAS
Yougoslavia–Romania	Danube	Irongate I	1969	STAMENKOVIC, 1991
		Irongate II	1983	STAMENKOVIC, 1991
Albania	Drin	3 dams		GULYAS
Russia	Kuban	Krasnodar	1973	CHEBANOV
		Fedorovsk (1)	1967	CHEBANOV
	Don	Tsimlyansk	1952	CHARLON and WILLIOT, 1978
Russia	Volga	Volgograd (1)	1958	CHARLON and WILLIOT, 1978
		Saratov (1)		
		Kuybishev		
	Kama	Votkinsk		
	Belaïa	Ioumagouzinsk	building in progress	Courrier International, 1999
Azerbaijan	Kura	Mingechaur	1961	KASIMOV
Iran	Sefi Rud	Sangar	1963	POURKAZEMI
		Tarik	1966	POURKAZEMI
		Manjil	1960	POURKAZEMI
Uzbekistan	Amu Darya	several earth dams	1973	ZHOLDASOVA and PAVLOVSKAYA
		Takhiatasch	1974	ZHOLDASOVA and PAVLOVSKAYA
		Tuyamuyun	1984	ZHOLDASOVA and PAVLOVSKAYA
Kasakhstan	Sir Darya	2 dams		
Russia	Ob	Novosibirsk	1959	RUBAN, 1999
	Irtych	Ust-Kamenogorsk	1954	RUBAN, 1999
		Bukhtarminsk	1964	RUBAN, 1999
		Shuliabinsk	1987	RUBAN, 1999
	Yenisei	Krasnoyarsk	1970	RUBAN, 1999
		Sayano-Shushensk	1978	RUBAN, 1999
	Angara	Irkutsk	1956	RUBAN, 1999
		Bratsk	1966	RUBAN, 1999
		Ust-Ilinsk	1977	RUBAN, 1999
		Boguchanks	1978	RUBAN, 1999
	Lena–Vilyuy	Vilyuisk	1976	RUBAN, 1999
	Kolyma	Kolymsk	1984	RUBAN, 1999
China	Yangtzé	Gezhouba	1981	DENG *et al.*, 1991
		Three Gorges	building in progress	

(1) Dams equiped with fish passage

and damming. Landings decreased dramatically some 20 years after the dam construction; Nordfeldt across the Eider River (Germany), Alcala del Rio across the Guadalquivir River (Spain), Iron Gates I across the Danube River (Yugoslavia and Romania), Fedorovsk across the Kuban (Russia), Minguechaur across the Kura (Azerbaijan), and Ust-Kamenogorsk across the Irtych River a tributary of the Ob River. In the Volga, 20 years after the building of Volgograd dam, the last highest landing was recorded. KHODOREVSKAYA *et al.* (2000) demonstrated that damming the Volga at Volgograd induced a gradual decrease in sturgeon stocks. Similarly, the detrimental effects of both Iron Gate dams across the Danube River have been demonstrated (JANKOVIC, 1995). Only three rivers inhabited by sturgeons are not dammed, the Guadiana (South Portugal), the Ural (Kazakhstan), and the Amur (Russia–China).

7. Regulation

One to three measures (1.6 ± 0.74; m ± sd) were mainly associated within the 14 described cases. Among them, minimum fish size and restricted catching period were each quoted in 50%; quotas and no measures accounted for 21% each, number of licences for 14%, and restricted area for 7%. In 50% of the cases ($n = 10$) the police control was regarded as effective, and in 40% it was not. The fines were not felt as being deterrent in most of the cases (73%, $n = 11$). This is most probably because the level of the fines is much lower than the expected income with the exception of the previous situation in the former USSR where fines were at a very high level (CHARLON and WILLIOT, 1978).

8. Biological Knowledge

Most scientists (83%, $n = 12$; z test $= 2.825$, $P > 0.005$) stated that biology and ecology was known enough to provide suitable recommendations for a sustainable management of sturgeon populations. Similarly, 89% ($n = 9$; z test $= 2.838$, $P > 0.005$) specified that biological indicators are available as alarm signals in case of deterioration of the viability of sturgeon stocks.

9. Recovery Measures

Different measures might be taken to maintain and/or restore sturgeon populations: habitat improvement, increasing the number of individuals by stocking, and forming of captive broodstocks (conservation biology) as a prevention of complete disappearance of a species. Habitat improvement comprises decrease of pollution, building of fish-pass, and spawning grounds. Decrease of pollution is potentially the most promising action but also the most difficult to achieve quickly. This seems to be the main explanation for the improvement of sterlet status in the Hungarian part of Danube. A fish pass is supposed to be a response to the dams constructed across most of the rivers inhabited by sturgeon (Table 4). The dams of only three rivers were equipped with fish-pass: Guadalquivir, Kuban, and Volga. The elevators of Volgograd worked (VOVK, 1968) but the number of spawners migrating through the elevators was limited to about one tenth of the stock (NUSENBAUM, 1968). Moreover, the fish going upstream either through the elevators or transported did not found suitable conditions due to the building of the Saratov dam (IVANOV, 2000). As the Volgograd dam reduced the spawning grounds area from 3600 ha to 415 ha (IVANOV, 2000), the potential for reproduction was extremely reduced. Artificial spawning grounds and/or improvement of those existing were conducted in Kuban and Volga rivers (VLASSENKO, 1974; IVANOV, 2000). As they were necessarily build in the lower part of rivers, their impact is limited.

Stocking has been extensively used as a measure to sustain fisheries or to restore populations (Table 5). The following numbers show some tendencies. In the Ponto-Caspian region, the quantity of stocked fish by each country is presently in the range of 10 to 50 millions. With regard to Russia, the present release is about half of that of the past, which amounted to 70–100 millions fingerlings (CHARLON and WILLIOT, 1978; BARANNIKOVA, 1987). This is due to both decreasing number and deteriorating physiological condition of wild spawners (IVANOV *et al*., 1999). Azerbaijan was recently able to reinitiate its fingerling production. Iran is increasing its stocking effort for the last decade with specific concerns on *A. persicus*. The production in the Azov Sea area will be decreasing in the next years due the dramatic poaching in this area leading to an extremely low number of "authorised" breeders that can be used for breeding purposes from the Russian part. China stocks a million of Chinese sturgeon fingerlings per year in the Yangtze River. Hungary yearly sustains danubian population of *A. ruthenus* with 10^5 fingerlings, the population of which seems to be quite equilibrated. Italy provides regularly the Po River with some 10^5 fish of *A. naccarii*. Stocking in Austria (*A. ruthenus*) and France (*A. sturio*) are sporadic, in the latter case because of lack of breeders. Some recent stocking have to be mentioned in Romania. Most of stocking fish comprises fingerlings of a few grams. It has to be mentioned that some countries experienced releases with larger fish, Iran with *H. huso* and *A. nudiventris* (30–50g,

Table 5. Assessment of current yearly (otherwise mentioned) number of fish stocked

Country	**Species** (relative importance in %)	**Number** (yearling)
Russia (Volga)[a]	*Huso huso* (27) *Acipenser gueldenstaedti* (55) *Acipenser stellatus* (18)	$\sim 50 \cdot 10^6$
Kazakhstan (Ural)	*Huso huso* *Acipenser gueldenstaedti* *Acipenser stellatus*	$\sim 6 \cdot 10^6$
Azerbaijan (Kura)	*Huso huso* *Acipenser gueldenstaedti* *Acipenser stellatus*	$\sim 12 \cdot 10^6$
Iran	*Huso huso* *Acipenser persicus* (~80%) *Acipenser stellatus* *Acipenser gueldenstaedti* *Acipenser nudiventris*	$\sim 24 \cdot 10^6$
Russia (Kuban)	*Acipenser gueldenstaedti* (65) *Acipenser stellatus* (35)	$\sim 30 \cdot 10^6$
China (Yangtze)	*Acipenser sinensis*	$\sim 1 \cdot 10^6$
Hungary (Danube)	*Acipenser ruthenus*	$\sim 1 \cdot 10^5$
Italy (Pô)	*Acipenser naccarii*	$\sim 1 \cdot 10^5$
Austria (Drau)	*Acipenser ruthenus*	$\sim 10^2 – 4 \cdot 10^2$ (1982, 83, 87, 91, 95)
France (Garonne/Dordogne)	*Acipenser sturio*	$9 \cdot 10^3$ (1995)

[a] IVANOV (2000)

15–20 cm), Italy with *A. naccarii* (some months to 3+ aged fish), and Austria with *A. ruthenus* (20–55 cm). Except for Italy, at present all countries are under the dependence of the availability of wild breeders to produce fingerlings. Mention has to be made of recent progress in rearing and producing fingerlings of *A. gueldenstaedti* in the Volga region (I. A. BURTSEV, pers. com.).

There are very few studies focusing on control of the efficiency of such stocking actions. Though there are some positive signs in Italy and Austria, both these countries wait for some confirmation about the efficiency of stocking actions. Hungary has been yearly surveying its sterlet population and takes advantage of a pectoral fin abnormality in artificially produced fingerlings: about one third of fish sample are from stocking origin the remaining part being due to natural reproduction. In contrast to the widely used stocking, there are very few studies dealing with the control of efficiency of such a practice. In the Azov Sea and the Northern Caspian Sea, return rates were assessed to be in the range 1%–1.8% for *A. gueldenstaedti* and *H. huso* (in BOIKO, 1973; PIROGOVSKII, 1974) in the early 1970s. The uncertainty in evaluating the impact of stocking was recently illustrated in assessing the harvesting number of hatchery-produced *A. stellatus*; presented values of 30% according to KHODOREVSKAYA *et al*. (1997), whereas VESHCHEV (1998) was unable to give any figure. Moreover, the former author stated that an increase the number of fingerlings stocked did not affect the number of *A. stellatus* entering the river. In a recent attempt to estimate the contribution of the hatchery in the Soviet-Russian sturgeon ranching programme, SECOR *et al.* (2000) recognised "that important untested assumptions remain". The survival of fingerlings of *A. sturio* one year post release in 1995 in France was about 3% (ROCHARD, pers. com.). In fact, there are no working tools to accurately assess the return rate of stocked fish. Nevertheless, there are various converging arguments to support stocking measures. This practise prevented *H. huso* from extirpation in the Volga basin. There are signs of success in the Drau River in Austria and in the Hungarian part of the Danube with *A. ruthenus*, and in Pô basin with *A. naccarii*.

The last recovery measures deal with *ex situ* conservation biology. The first consists of farming endangered species till the natural habitat again guarantees survival of the species. At present, only three species can be bred without problems, *A. naccarii*, *A. ruthenus*, and *A. baeri*. Two species are at the experimental level, *H. huso* and *A. gueldenstaedti*. Five species are at the research level, *A. stellatus*, *A. sturio*, *A. persicus*, *A. sinensis* and *A. medirostris*. Cell conservation is only represented by two examples of current use of cryo-preserved sperm. Due to low number of individuals in endangered populations, it is a risk that genetic diversity decreases. There are only four situations where genetic investigations started. In order to prevent complete disappearance of a species, some extreme solutions might be envisaged. Androgenesis is being explored in Russia and Hungary. In contrast, there are no investigations directly focused on genetic sex determining mechanisms that remain unknown in Eurasian sturgeon. Because most of sturgeon stocks have an international status, their recovery needs a lot of effort, and cooperation programmes are vital. In half of the cases, they are mentioned at national or international levels. Both levels of co-operation are mentioned in one third of the cases. In most of the cases, we have to ask whether these cooperation programmes are effective.

10. Attempt for a Synthesis

The present synthesis cannot be considered as unbiased, nevertheless it provides some lines to potentially improve the management of sturgeon stocks as most regulations used to date, failed to maintain Eurasian populations of sturgeon. This suggests that sustainable management of sturgeon populations is not only a scientific question even if science is heavily involved as reported for Northern American sturgeon populations (BEAMESDERFER and

FARR, 1997). Indeed these last authors stated that "efforts which do not address habitat degradation have generally failed to restore sturgeon population to historic level of productivity".

The dramatic decrease in landings of Eurasian sturgeon have been occuring in different countries under different political systems over the last hundred years. As a result, the example of the disappearance of a sturgeon resource at a given place proved to be of no help for another country. Reasons for the decline were essentially the same every where. All sturgeon populations were commercially exploited. It is noteworthy that the only recovering sturgeon population is a freshwater species, the sterlet, *Acipenser ruthenus*, in the Hungarian part of Danube, is now supporting a recreative fishery.

From all the reported figures of sturgeon landings, none of them shows steady state landings over a period longer than ten years, that is youth for most of sturgeon. It means that none of the fisheries could be considered as having been exploited in a sustainable way for at least one biologically significant period. Thus, no reference exists of such a situation with regard to the applied management procedures. Which could be the minimum duration as representing an equilibrated management? As it was shown that detrimental effects of damming might be delayed for about 20 years (Volga example), this time span must be considered a minimum time for recovering measures.

With regard to the present status of sturgeon stocks, none of the managing measures, if any, proved to be efficient. In contrast, biological and ecological knowledge were claimed to be known enough to provide suitable recommendations for a sustainable management of sturgeons populations. Three explanations might be suggested: recommendations may either be not applied, not understood thus not applied afterwards, or applied but were not efficient. In the former case, recommendations are ignored, thus decision related to sturgeon fisheries and/or populations are of political, social and/or economical relevance. Three items support this alternative. Co-authors have divergent standpoints about the weight of sturgeon fisheries in a decision-making system. At the best, the interest of sturgeon fisheries was taken into account with visible compensations (elevators, stocking, etc.) but most of the time without ensuring that conditions for success of such compensations were fulfilled (good quality of the wild for stocked fish, functional spawning grounds, etc.). Fines were mostly not deterrent, and in half of reported cases, fisheries officers were not trained in fisheries. These statements show that there is little or no consideration for fisheries, in other words the relative weight of fisheries is negligible. The second hypothesis stated that recommendations might not have been understood because the proposals were too complex to be easily applied. The third hypothesis suggests that elaborated tools were inefficient. Scientists were directly engaged in the last two events.

When the situation is more deteriorated, i.e. when commercial sturgeon fisheries already ceased, only recovery plans may prevent a species from complete extirpation. The efficiency of a recovery programme depends on the capacity of ranking the reasons of the collapse of the population. For example, stocking measures may not or may be recommended if pollution is responsible or not responsible for the decline of species. And thus, a second contradiction occurred between the claim that biological knowledge is sufficient and the fact that it seems to be difficult to rank the various reasons of decline: this is aparently due to the fact that most of the reasons usually highlighted for the decline of sturgeon populations (damming, overfishing, poaching, pollution, water pumping, etc.) are out of the field of fisheries sciences *stricto sensu*. Indeed, beside the aforementioned reasons, non responsible fishery, bad socio-economic situation and the lure of gain for caviar largely contributed to the decline of sturgeon populations.

In summary, neither were sturgeon fisheries managed in a sustainable way nor were resources preserved. As judged by the results, all regulations and recovery measures failed. Everything took its way as sturgeon population were firstly affected mainly by overfishing and/or damming and then completely collapsed due to pollution and non responsible fishing.

This seems to be the inexorable spiral of the decline. The future for most of the sturgeon population is bad, in particular as this scenario was not at all or not early enough anticipated to set up the necessary actions for the prevention from the extinction of most of the sturgeon species. Most probably, sturgeon stocks are far from recovering to a commercial exploitation level.

11. Suggestions for a Better Perspective

Suggestions are structured in four parts from precise to general items knowing that the most effective actions are decrease of pollution, habitat protection, and providing people with remunerative activity. Such actions cannot be set up abruptly and will not provide rapid improvements in the quality of the natural habitat. As a result, protection and conservation must be organised as soon as possible.

The first and more urgent suggestion consists in banning the caviar trade of caviar and meat from endangered wild sturgeon taking in account that USA, Western Europe and Japan are the main consumers of caviar[1]. Some tools are already available to discriminate between different caviar types (DESALLE and BIRSTEIN, 1996; LUDWIG *et al.*, 2002) and species (Environment Canada *et al.*, 2001). Efforts of CITES have to be developed, promoted and wide spread (see RAYMAKERS, 2002). Every national authority should provide the tools to assure that trade controls become effective. This is a mean to decrease the pressure on remaining endangered wild stocks.

The second suggestion deals with *ex situ* conservation which is of extreme urgency to prevent some species from extinction. Setting up of farmed broodstocks is becoming urgent for every threatened species. Unfortunately, best rearing conditions are mostly unknown because biology and ecology were previously poorly investigated. In addition, there is no guide to help conservationists to face with these new situations, and some useful approaches are generally ignored as illustrated by potential interest of behavioural sciences (SHUMWAY, 1999). The building of confined broodstocks should be guided by genetic diversity assessment compared with known patterns in related wild populations. As individuals of endangered species are scarce, non-invasive methods of investigation should be developed in order to assess the health state of the specimen as in humans. As expected results are time consuming without any guarantee in success, various complementary investigations should be promoted: these are sperm preservation, androgenesis, cloning (CORLEY-SMITH and BRANDHORST, 1999), genetic of sex determination and more generally, all fundamental and practical aspects related to reproduction. For example, the availability of *in vitro* ovulation of ovarian follicles bio test should considerably improve the efficiency of selection of the best gravid female with regard to the expected quality products from the females before the hormonal stimulation (WILLIOT, 1997). One of the final goals of the *ex situ*-measure (conservation biology) is to stock fish to support remaining population and/or to reintroduce the species in good quality river drainage systems previously inhabited by the species considered. The efficiency of this practise should be assessed, thus long term tagging should be investigated such as biochemical and genetical markers as suggested by SECOR *et al.* (2000). Strontium marking could be also a good candidate to help solving this question (YAMADA *et al.*, 1979; CLEAR *et al.*, 2000) after checking if strontium is also detectable on the first pectoral fin ray.

The third suggestion focuses on fisheries data and/or biology of population. Ideally, a better knowledge in biology is necessary for the management and the conservation of sturgeon. A biological survey of population (exploited or protected) is needed to document repro-

[1] Some co-authors disagree with this statement because they consider that banning sturgeon and caviar trade from Caspian bordering countries would cut their needed financial support for stocking.

ductive cycles (spatial distribution, ecophysiology etc.), main ecological phases (spawning grounds, nurseries etc.), feeding habits, and genetic data. It is worse noting that the availability of such data would provide the needed missing references when setting up a captive broodstock. Combined efforts should be taken to assess quantitative and functioning characteristics of populations, e.g. recruitment, mortality rates, growth etc. Special attention should be brought to the very early biological indicators that could reveal as early as possible biological disturbances due to pollutants. In particular, reproductive features should be considered.

Different issues are relevant to management. Facing with such difficult situations described, people involved in conservation biology have to choose priorities without neglecting relevant issues. There is no help, no guide that can be used to avoid strategic misdirection. It is a way that has to be promoted. In the same field, education and training appears to be one of the most promising action to allow exchange between all parties concerned by fisheries. Fisheries officers, and fishermen as well should be trained in sustainable fisheries management. Wild sturgeon fish are "*res nulius*", this means that the fishing action transforms the status of the fish into the property of the fisherman. This previous non-belonging status might psychologically justify the fisherman to fish without any restriction. Education, including the perception of responsibility might tentatively change this attitude. Training courses in conservation should be developed at the university level in order to educate people in sustained management, protection, biodiversity, and conservation biology. These people would be prone to adopt timely the best solution in conservation planing. For example the present situation of *ex situ*-conservation of *A. sturio* in France would most probably be very different if we had been more experienced in larval raising and feeding in 1985 (WILLIOT *et al.*, 1997).

The complementary action consists in setting up a fisheries management procedure involving as closely as possible all parties concerned. This way of functioning explains the success of coastal fisheries management in Japan (YAMAMOTO, 2000). In this framework, all parties work together and are expected to adapt the management for a sustained fishery. It has been recalled several times that in extremely threatening situation, sturgeon conservation should be set up though there is evidently a lack of biological knowledge. This observation is not only limited to sturgeon and led SOULÉ (1986) to call conservation biology a crisis discipline. To tentatively avoid such dramatic situation it is suggested that some conditions have to be fulfilled before any acceptance of exploitation. An extended biological and ecological knowledge should be available. Rearing success should be obtained prior to any exploitation that should be accompanied by a biological survey. All the needed costs for these actions should be included in fish products. One may actually attract the attention on two genetic aspects. When a pure species is threatened, hybrids should not be recommended except when they are only produced from genetically characterized captive broodstocks. Great care has to be paid in transferring or to the escapement of sturgeon species. Hybrids between Siberian sturgeon and Russian sturgeon could be demonstrated by molecular genetics in the Volga drainage where Siberian sturgeon is not naturally present (JENNECKENS *et al.*, 2000). In addition, these hybrids might be fertile because both parents possess the same ploidy level. A lot of different alien sturgeon species were reported in the German coasts of the North and Baltic seas (GESSNER *et al.*, 1999). As a result of an totally unexpected overflow in a French fishfarm, a lot of Siberian sturgeon escaped in the Gironde-Garonne-Dordogne drainage. Some of them survived and switched their feeding to wild benthic preys (ROCHARD *et al.*, com. pers.).

The last suggestion addresses the relative weight of sturgeon fisheries. Two lines might be suggested. One consists in associating sturgeon fish to other uses of the same biotopes to potentially increase their relative significance. One of them which is becoming well accepted in the public is the availability of freshwater; this issue is able to mobilise people and decision-makers as well: what is good for freshwater resource is good for sturgeon too.

This will allow proposing some changes by law, education, and organisation to tentatively avoid such dramatic deterioration of natural resources.

The second line deals with the promotion of environmental economic investigations. This will improve taking into consideration indirect costs of any disturbances to fish stocks resulting of town and country planing activities. In addition, these costs should be included in those planing actions creating negative impact. One attempt in this area focused on *A. sturio* in France that showing that the restoration program was most probably the less costly solution (POINT, 1991).

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