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SIGNIFICANCE OF AQUACULTURE FOR THE CONSERVATION AND RESTORATION OF STURGEON POPULATIONS

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Abstract

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Sturgeons (family *Acipenseridae*), endemic in Eurasia and North America, are mostly fast-growing, long-lived migratory anadromous fish species of high ecological and economic value. They reach maturity often at high age. Most of their stocks have declined considerably during the last years. Main causes are over-exploitation, river regulations (damming) and deterioration of water quality (pollution). Several species are highly endangered, facing the risk of extinction. Besides national and international measures for improving the environment and for establishing management programmes aquaculture is of decisive importance for the conservation and restoration of sturgeon populations. First essential bases of sturgeon aquaculture by means of hypophysation were elaborated and introduced into practice already in the first half of the last century by N. L. Gerbilskij (1900-1967). Sturgeon farming has two tasks. Firstly it is necessary to produce fingerlings suited for stocking natural waters. By this means it is possible to support or even enhance the populations. Secondly sturgeon meat and caviar can be produced for the market. This substantially contributes to reduce the fishing pressure to natural stocks of sturgeons. Aquaculture of sturgeons comprises the following steps: establishment of brood stocks, propagation, incubation of eggs, rearing of fry and fingerlings, production of marketable fish, processing of meat and caviar. To improve technology and procedures for sturgeon aquaculture extensive scientific research mainly in the field of genetics, reproductive physiology, nutrition and feed manufacturing as well as prevention of diseases but also economics and marketing is required. Without aquaculture and international cooperation sturgeon species in natural waters cannot be saved.

Key words: Acipenseridae, sturgeons, aquaculture, caviar production

Systematics and Distribution

The subfamily *Acipenserinae* within the family Acipenseridae includes two genera:

- genus *Acipenser* - about 17 species (Eurasia and North America),
- genus *Huso* - 2 species (Eurasia).

Sturgeons are fish without scales and intermuscular bones. They have five longitudinal rows of bony plates on the body. Sturgeons occur only in the Northern Hemisphere (Europe, northern Asia and North America). Many species are diadromous fishes, some inhabit only freshwaters.

The taxonomical relationship between the distinct

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species of the genera *Acipenser* and *Huso* is complicated. One group comprising the two species of *Huso* (*H. huso* and *H. dauricus*) and the European Atlantic sturgeon (*Acipenser sturio*), the stellate sturgeon (*A. stellatus*), the ship sturgeon (*A. nudiventris*) and the sterlet (*A. ruthenus*) are characterized by 2n = 120 chromosomes. In the other group with e. g. the Russian sturgeon (*A. gueldenstaedti*), the Siberian sturgeon (*A. baeri*) and the Adriatic sturgeon (*A. naccarii*) there are about 240 chromosomes in the diploid karyotype (Holцic, 1989). Species of the second group may be, therefore, contrary to those of the first group tetraploids or polyploids. From this point of view it seems doubtful whether the separation of the two genera *Huso* and *Acipenser* can be maintained. Anyhow, many acipenserid species hybridize without problems, which is a criterion for close taxonomical relationship. It is interesting that crossing between the large growing great sturgeon (*H. huso*) and the small sterlet is possible and results in fertile F_1-hybrids (Steffens et al., 1983).

The main centre of sturgeon distribution is the Caspian Sea and the corresponding large river systems, especially the Volga and the Ural. About 90 % of world-wide all sturgeons are to be found or were to be found within this watershed. The great sturgeon, the Russian sturgeon, the stellate sturgeon, the ship sturgeon and the sterlet are living here. In the southern part of the Caspian Sea moreover the Persian sturgeon (*A. persicus*) is present. All of these species with the exception of the Persian sturgeon also inhabit the Black, Asov and Mediterranean Seas and the rivers that empty into them.

In former times these sturgeons ascended the Danube and its tributaries as far as Bavaria. However, large individuals were certainly already rare in the 17th century.

In Germany the European Atlantic sturgeon was very important for fishery until about 1900 (Mohr, 1952). This species was abundant along the European coasts, which means also in the Black Sea, the Mediterranean Sea and at the Atlantic coast of Spain and France and the river systems there.

According to recent genetic investigations it can be assumed that since the early Middle Ages *Acipenser sturio* was replaced by the American Atlantic sturgeon (*A. oxyrhynchus*) in the Baltic Sea (Ludwig et al., 2002). However, possibly *A. sturio* and *A. oxyrhynchus* are only subspecies of a single species (Artyuchin and Vescei, 1999). Between different populations of *A. sturio* there are greater differences than between *A. sturio* and *A. oxyrhynchus*.

The Siberian sturgeon is an indigenous species in many Siberian rivers from the Ob to the Kolyma. It was also introduced in European waters (e. g. Baltic Sea).

The continental shelf of the Yellow China Sea and the East China Sea and the rivers of this region are the range of distribution of the Chinese sturgeon (*A. sinensis*). In former times the species was numerous in the Yangtze river, today the population is rapidly decreasing.

North America is inhabited by five acipenserid species. Besides the American Atlantic sturgeon these are the lake sturgeon (*A. fulvescens*), the white sturgeon (*A. transmontanus*), the green sturgeon (*A. medirostris*) and the shortnose sturgeon (*A. brevirostrum*). The white sturgeon is endemic in the river basins along the Pacific coast. It is the largest fish occuring in freshwaters of North America.

Decline of Sturgeon Populations

Many sturgeon species are large-growing and long-lived (Table 1). The great sturgeon is the largest freshwater fish species in Europe. A female fish caught 1937 in the Caspian Sea was 4.90 m long and had a weight of more than 1000 kg. A male from 1940 was 4 m in length and 725 kg in weight. On the other side the sterlet inhabiting only freshwaters is the smallest acipenserid species and comes at most to 0.70 m and rarely 2 kg.

Sturgeons often have a life span of several decades. Maximum age of the great sturgeon is more than 100 years, that of the white sturgeon up to 150 years. The sterlet can reach an age of more than 20 years. It was reported that a sterlet in the Zoological Garden of Amsterdam which died in 1953, was 70 years old.

Table 1
Maximum size and age in different sturgeon species

Species	Maximum length, m	Maximum weight, kg	Maximum age, years
H. huso	> 3 (4)	> 250 (1000)	> 100
A. sturio	to 2.50	> 80	> 40
A. guldenstaedti	to 2	to 80	> 30
A. stellatus	to 1.60	to 25	ca. 30
A. ruthenus	to 0.70	rarely > 2	> 20
A. baeri	2	to 80	60
A. transmontanus	to 6	to 900	to 150

Such large-growing and long-lived animals reach sexual maturity very late. Since there is a strong influence of climatic conditions (especially water temperature) and feed supply the figures referring to the onset of sexual maturity can vary considerably (Table 2). Frequently the fish require two to five years for the gonads to ripen again after spawning.

Table 2
Attaining sexual maturity (years) in different sturgeon species

Species	Male	Female
H. huso	10-16	13-22
A. sturio	7-15	8-20
A. gueldenstaedti	11-13	12-16
A. stellatus	5-13	8-17
A. ruthenus	3-8	4-14
A. transmontanus	15	25-30

Main reasons for the decline of sturgeon populations are overfishing, dam buildings and water pollution.

Since long times the large-growing fishes are caught extensively by fishermen. Not only the meat is a valuable foodstuff, also the eggs are desired for production of high-priced caviar. Sturgeons are often caught before onset of sexual maturity, and for caviar production it hs necessary to catch the fish before spawning.

By river regulations and dam buildings for hydroelectric power stations habitat destruction occurs and ascending spawners cannot reach the spawning sites and spawning sites are lost. Until the begin of dam building in the Volga there were 219 spawning places for sturgeons with an area of 3 400 ha in the upper regions of the river. Today there are only 412 ha downstream of Volgograd and 80 ha upstream for fish which can pass the dam, that means only 15 % of the former area are left (Steffens and Meyer, 1975a).

Deterioration of water quality is another important reason for the decline of sturgeon stocks. Increasing pollution by environmental contaminants and toxic substances cause acute losses or chronic damage. Very dangerous is the pollution of spawning places for the reproductive success and the survival of fry.

On the strength of the cited reasons acipenserid stocks has declined world-wide to crisis level (Figure 1). Catch of many sturgeon species decreased to less than 15 % of the former peak yield. Highest production of great sturgeon e. g. was about 15 000 t per year in the period of 1902 to 1907, today it only comes to 3 % of the catch at that time.

According to Pikitch and Doukakis (2005) the historic peak harvest of all sturgeon species in the Caspian Sea was nearly 50 000 t per year. In the period of 1900 to 1915 the average yield amounted to 26 000

Table 3
World-wide sturgeon catch 1965 -2004 according to FAO data

Year	t
1965	20 000
1970	21 000
1975	27 500
1980	29 100
1985	25 600
1990	18 200
1995	6 200
2000	2 600
2004	1 500

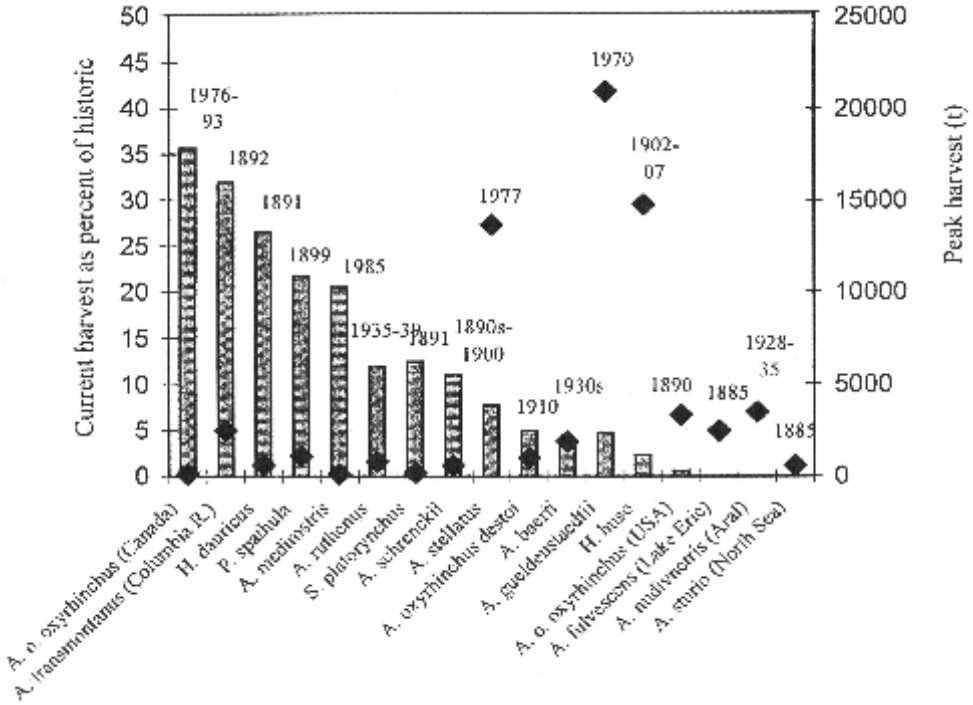

Fig. 1. Historical and present catch in different sturgeon species. Bars indicate current production (or production recorded before fishery closure) as percentage of historic peak production. Diamonds represent peak production values and their respective dates(Pikitch and Doukakis, 2005)

t, from 1920 to 1965 it dropped to an average of 11 000 t per year, mainly due to over-exploitation and catch of immature fish in the sea. Protection measures resulted in an increase of the catch to more than 20 000 t in the years between 1975 and 1986 (Pourkazemi, 2005). Thereafter a rapid decrease took place (Table 3). Today sturgeon yield only comes to less than 1 000 t per year.

In the Asov Sea sturgeon populations also dropped to a drastic low level near extinction (Williot et al., 2002). In the Don river basin there are nearly no more sturgeons.

Catch of European Atlantic sturgeon in the Elbe averaged to 4 000 to 5 000 fishes per year in the middle of the 19th century. About 1900 the yield decreased to about 1 000 fishes, 1918 only 34 sturgeons were caught. In the following years merely sporadic sturgeons were recorded, e. g. in May 1959 a specimen weighing 285 kg near Helgoland. Today this species became extinct in the North Sea (Debus, 1955). A small stock still exists in the Gironde (France).

The white sturgeon along the Pacific coast of North America is seriously threatened. Since 1994 legal catch limitations exist. At present a protection programme is prepared.

For protection the sturgeon stocks in the northern Caspian Sea area catch in the sea is forbidden since 1962 (Russia). By this means juvenile sturgeons were preserved. In the rivers fishing is not allowed during spawning time, at spawning sites as well as at hibernating places (Russia). In the Volga a general capture prohibition in June and July was issued. However, all of these measures did not result in effectiv successs.

Since 1997 all species of Acipenseriformes are listed in the appendices of CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora). There is obligation for registration, documentation and book-keeping, imports require

permission. Stringent protection measures are valid for three species (*A. sturio, A. naccarii* and *A. brevirostrum*).

To improve cooperation the Commission of Aquatic Bioresources of the Caspian Sea was founded in 1992. Members are Russia, Azerbaijan, Kazakhstan, Turkmenistan and Iran. However, besides this international care huge effort at national and regional level is necessary to stop further decrease of sturgeon populations.

Despite national and international measures and managements efforts substantial problems arose since the nineties of the past century from uncontrolled fishery. Its consequences are immense. According to estimate of WWF (World Wildlife Fund for Nature) at present 90 % of the catch is result of illegal fishing (poaching). Important stimulus is the high price of caviar.

Sturgeon Culture

Bases of reproduction

First experiments with regard to propagation of sturgeons, that means to gain eggs and sperm, to fertilize and incubate eggs were carried out in Russia 1869, in the United States about 1875 and in Germany 1882. But there was little success. Main problem was that the fish were not mature during catch and that it was not possible to induce ovulation.

In the years after 1930 the Argentinian physiologist B. A. Houssay (Nobel prize winner 1947) carried out injections of pituitary glands in fish to stimulate sexual maturity. Probably without knowledge of these experiments the zoologist N. L. Gerbilskij (1900-1967) in St. Petersburg introduced pituitary gland injections (hypophysations) into practice of fish culture and also sturgeon culture since 1938. In that way a quite new stage of fish reproduction started (Steffens, 1984, 1992). By means of hypophysations it was possible to induce ovulation in sturgeon females and to strip the eggs. Eggs can also be obtained by a small abdominal incision. After suturing, females can be used repeatedly for egg production.

In the meantime (since about 1980) progress took place. Instead of pituitary glands releasing hormones (GnRH) were utilized to induce maturation of spawners (Doroshov and Lutes, 1984; Barannikova et al., 1989, 2005; Bahmani et al., 2005). Releasing hormones or their analogues can be measured out more accurately and operate on another endocrine level. Gonad maturation is then caused by the own gonadotropins of the fish (Figure 2)

In valuable larger spawners it has proven true to check the stage of maturity before and after hormone injection by biopsy. After artificial fertilization stickiness must be removed from the eggs by continuous washing before putting them in incubators. Duration of incubation depends on water temperature, at 12-18 °C fry generally is hatching after 5 to 7 days.

Rearing of stocking material

Release of newly hatched fry is ineffective since mortality is very high. Therefore, it is necessary to rear advanced fry or fingerlings before stocking in natural waters. Thus survival of released fish can be increased considerably.

For the rehabilitation and enhancement of natural sturgeon stocks in the middle of the past century a comprehensive programme for construction of sturgeon farms started in the former Soviet Union (Steffens und Meyer, 1975b). These farms were established at the bank of the rivers in which the sturgeons ascend to spawn and are based on the catch of spawners in these waters. Fish selected for reproduction are first stocked into pre-spawning ponds. After hormonal stimulation eggs and sperm are obtained and the fertilized eggs incubated (Steffens, 1986). Fry is reared either in ponds on the basis of natural food or in basins with feeding. At an age of 30 to 45 days advanced sturgeon fry reach a weight of 2-5 g and is released in front of the coast of the sea.

In the northern and western Caspian region there are 13 sturgeon farms, 10 belonging to the Russian Federation (8 on the Volga river and 2 on the Terek river in Dagestan) and 3 to Azerbaijan (on the Kura river). In the Sea of Asov basin there are 7 sturgeon farms and on Siberian rivers are 3 sturgeon farms (Barannikova et al., 1995; Lukyanenko et al., 1999).

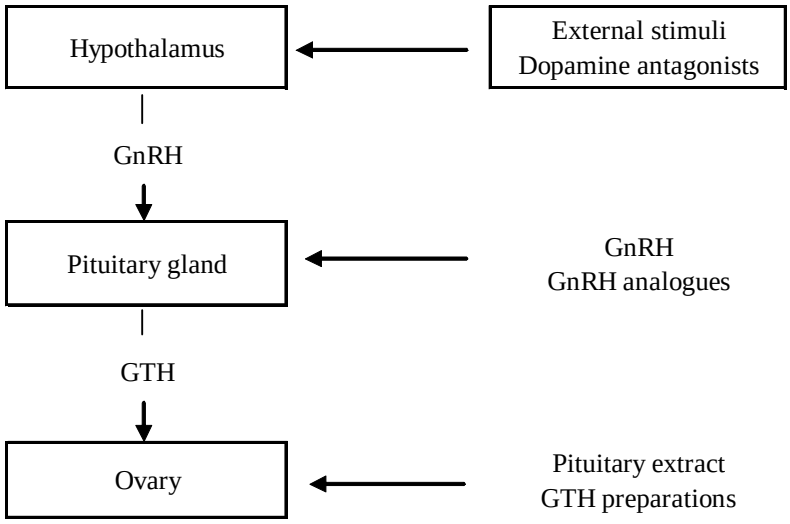

Fig. 2. Scheme of the endocrine processes in the hypothalamic-hypophyseal-ovarian axis during natural and induced maturing of the fish ovary (Donaldson and Hunter, 1983)

Five sturgeon farms were built in Iran Using the Russian experience since 1971 (Steffens, 2005). Produced advanced fry and fingerlings are released in the lower region of rivers (southern Casian Sea basin).

Annual production of stocking material in the northern and western Caspian region varied from 1989 to 1995 between 57 and 101 million (Table 4). In Iran (southern Caspian Sea) nowadays more than 20 million of juveniles (mostly *A. persicus*) are reared and released (Table 5).

According to estimations for the northern Caspian region 10 years ago about 50 % of Russian sturgeon catch, 40 % of stellate sturgeon catch and 98 % of great sturgeon catch originated in stocking (Ivanov et al., 1999). In Iran (southern Caspian Sea basin) a positive effect of stocking for the population of the Persian sturgeon is also supported (Moghim et al., 2005).

In the northern Caspian Sea basin the returning rates of stocked advanced fry for spawning amount to 0.1-0.2 % for the great sturgeon, 1.2 % for the Russian sturgeon and 0.8 % for the stellate sturgeon.

Techniques and results of fingerling production of

Table 4

Production (mill.) of advanced fry of different sturgeon species in farms of the northern and western Caspian Sea basin for stocking 1989-1995 (Ivanov et al., 1999)

Year	Russia	Azerbaijan	Kazakhstan	Total
1989	82.43	18.16	0.77	101.36
1990	75.86	17.55	0.76	94.17
1991	72.28	9.11		81.39
1992	75.07	2.97		78.04
1993	62.86	2.38		65.24
1994	68.68	1.56		70.24
1995	55.66	1.24		56.9

Table 5

Production (mill.) of sturgeon fingerlings of different species in Iran for stocking in 2002 and 2003 (Salehi, 2005)

Species	2002	2003	% of total number/year
A. persicus	12.331	18.420	79.4
A. nudiventris	1.179	1.414	6.8
H. huso	2.373	0.042	6.3
A. gueldenstaedti	1.564	-	4.0
A. stellatus	1.183	0.196	3.5

Chinese sturgeon (*A. sinensis*) are described by Zhu et al. (2006). The first attempt for artificial propagation of this species was undertaken in the seventies of the past century. Initial feed is *Artemia* nauplii, zooplankton (rotifers and cladocerans) and minced *Tubifex*. These organisms are fed eight times a day. At a size of 5-6 cm acclimation to formulated diets begins. Moist pellets of about 1.5 mm diameter are used. First feed contains 30 % *Tubifex*. Content of *Tubifex* in the feed is reduced gradually. After one week, 85 % of the young fish generally accept feed and can be weaned to formulated diets. The remaining 15 % of the fish must be sorted out to repeat the acclimation process. After transition to feeding on prepared diets, young fish were fed four times a day with commercial special sturgeon feed (42 % protein). Rearing temperature of 18-22 °C is recommended. At average water temperature of 22 °C juveniles can grow to about 10 g in 65 days. To secure the growing demand for stocking material in future it is not sufficent to catch spawners in natural waters. It is rather necessary to establish brood stocks of the different sturgeon species. Thereby it has to be taken into consideration that each species comprises different subspecies and biological groups (e. g. spring and winter races). The genetic diversity must be conserved. Favourable environmental circumstances (especially optimum water temperature and nutrition) generally result in faster growth compared to natural conditions. Thus there is also an earlier onset of sexual maturity which favours artificial reproduction.

Today for the first feeding of sturgeon fry in many cases natural food (plankton organisms, chironomids, oligochaets) is used (Vedrasco et al., 2002). Extensive scientific research is required for the development of dry diets which give good results in rearing of fry, juveniles and adults.

Production of marketable fish and caviar

The significant decline of sturgeon catch reduces the supply of sturgeon meat and caviar and increases prices on the market. Since years sturgeon culture in ponds, cages and basins is realized in numerous countries aiming at production of marketable fish and high-priced caviar.

Different sturgeon species and hybrids are used for this purpose. In Europe *A. baeri* and *A. transmontanus* are dominating species (Bronzi et al., 1999). *A. baeri* is cultured in France (Steffens, 1996; 2001), mainly *A. transmontanus* and to a less extent *A. naccarii* and *A. baeri* in Italy (Arlati and Bronzi, 1995). *A. gueldenstaedti* and other species are reared in Bulgaria (Steffens and Hubenova, 2006). According to Russian experience bester (*Huso huso* ♀ + x *A. ruthenus* ♂) is well suited for aquaculture (Steffens and Meyer, 1975c; Steffens and Jahnichen, 1982, 1995; Steffens et al., 1983, 1990a, 1990b).

In the USA commercial sturgeon aquaculture is based preferably on *A. transmontanus*. Under controlled conditions females reach maturity already at an age of 7 to 9 years weighing 30-40 kg. In natural waters fish come to this size not before an age of 20 to 25 years (Doroshov et al., 2005).

For caviar production manufacturing of meat and caviar has to be considered in connexion. It is recommended to separate males and females at a size of 2.5-3 kg by means of sonography and to sell the males on the market. Females are reared until eggs are developing. Egg yield amounts to about 10 % of the female's weight.

Promising results of sturgeon and caviar production are known from France (Departement Gironde,

Table 6
World-wide sturgeon aquaculture production 1995-2004 according to FAO data

Year	t
1995	1 135
1996	1 297
1997	2 025
1998	2 034
1999	2 465
2000	3 158
2001	3 091
2002	3 816
2003	14 747
2004	15 551

near Bordeaux). The fish (*A. baeri*) are reared at a density of 15-45 kg/m^3 and come to 2-3 kg in 2.5 years. Then sexes are separated, males are sold on the market and females reared for caviar production. Maturity starts at an age of 5 to 7 years (Steffens, 2001). Sturgeon production might be several hundred tons per year, caviar production about 40 t.

In Bulgaria also caviar production is developing. Sturgeon aquaculture is based on different species, e. g. *Huso huso* and *A. gueldenstaedti*. Oscietra Commerce Ltd produced 1.2 t of caviar in 2005.

On principle sturgeon aquaculture is in the beginning. The considerable increase of world-wide sturgeon aquaculture production in 2003 according to FAO data (Table 6) depends on adding figures of China for the first time.

Comprehensive research for progress in sturgeon aquaculture is necessary in the field of nutrition (improvement of dry diets), pathology, reproduction, genetics, economics and marketing strategies.

Since sturgeon aquaculture is expensive and short-dated earnings are not possible marketing requires special attention (Logan et al., 1995; Sanders et al., 2003; Doroshov et al., 2005).

Conclusions

Sturgeon stocks in the waters of Eurasia and North America are declining rapidly, several species are endangered and at a level near extinction.

Besides management measures aquaculture is of decisive significance for the conservation of sturgeon stocks.

Rearing and releasing of juveniles is an essential contribution to stabilizing and increasing stocks in natural waters.

By aquaculture production of sturgeon meat and caviar demand of market is satisfied and fishing pressure on natural sturgeon stocks can be reduced.

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