

Sturgeon farming in Western Europe: recent developments and perspectives

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Abstract – Sturgeon production in Western Europe originating from aquaculture in 1999 was approximately 1 300 t revealing an increasing trend. Three species represent 95 % of the annual production: white sturgeon (*Acipenser transmontanus*) 43 %, Siberian sturgeon (*Acipenser baerii*) 34 %, and Adriatic sturgeon (*Acipenser naccarii*) 18 %. The remainder is provided by various species including hybrids. The main countries in decreasing order of production are Italy, France, Spain, Germany and Poland. Fish are fed commercial formulated diet. The most significant changes in the sturgeon industry during recent years have been in the ownership of farms, in the emergence of the pond as a production system, and in the increasing caviar production from farmed sturgeon. In 1999, the production of farmed caviar from France and Italy, originating from Siberian and white sturgeon, respectively was close to 6 t. The number of active sturgeon farms in Western Europe is estimated to be approximately thirty, half of which are hatcheries. This paper presents different strategies and management approaches in sturgeon production and caviar processing. The potential caviar market and its dynamics are assessed and likely changes are discussed. Finally, some of the scientific investigations needed to improve and support this development are highlighted. Five different fields are distinguished: biological reserve, genetics, reproduction, farming, and quality of end products. © 2001 Ifremer/CNRS/INRA/Cemagref/Éditions scientifiques et médicales Elsevier SAS

sturgeon farming / caviar / Western Europe

Résumé – Élevage d'esturgeon en Europe de l'Ouest : développements récents et perspectives. La production d'esturgeon d'élevage de Europe de l'Ouest était estimée à quelques 1 300 t en 1999, traduisant ainsi une tendance en augmentation. Trois espèces représentent 95 % de la production annuelle : l'esturgeon blanc (*Acipenser transmontanus*) pour 43 %, l'esturgeon sibérien (*Acipenser baerii*) pour 34 % et l'esturgeon de l'Adriatique (*Acipenser naccarii*) pour 18 %. Le reste provient de diverses espèces et d'hybrides. Les principaux pays producteurs sont dans l'ordre décroissant l'Italie, la France, l'Allemagne et la Pologne. Les poissons sont nourris avec des aliments composés du commerce. Les principaux changements dans la production d'esturgeon intervenus récemment sont des modifications dans la structure du capital des entreprises, l'émergence de bassins en terre comme structure d'élevage et l'accroissement de la production de caviar. En 1999, la production de caviar en France et en Italie à partir respectivement d'esturgeon sibérien et d'esturgeon blanc avoisinait 6 t. Il y avait environ trente piscicultures en Europe, la moitié d'entre elles étant également des écloséries. Les diverses stratégies et modes de gestion de la production d'esturgeon et de caviar sont décrites. Nous donnons une estimation du marché potentiel pour le caviar ainsi que les évolutions les plus probables. Enfin quelques unes des voies de recherches nécessaires au développement de cette production sont mentionnées. Cinq champs d'investigation sont distingués : réserve biologique, génétique, reproduction, élevage et qualité des produits finaux. © 2001 Ifremer/CNRS/INRA/Cemagref/Éditions scientifiques et médicales Elsevier SAS

élevage d'esturgeon / caviar / Europe de l'Ouest

1. INTRODUCTION

The first trials in sturgeon farming were carried out almost simultaneously in mid 19th century in Russia, Germany and North America to compensate for declines in the harvest from wild sturgeon. After a series of failures, major progress was made in the 1950s in the former USSR to support wild Caspian sturgeon populations (Binkowski and Doroshov, 1985; Baranikova, 1987; Burtsev, 1999). As a result of the investigations in sturgeon propagation, the commercial production of a hybrid between *Huso huso* and *Acipenser ruthenus*, the 'bester', started in the 1960s in the former USSR (Burtsev, 1999). Sturgeon farming in western countries began during the 1980s mainly as a consequence of conservation efforts for threatened wild populations. These concern the Adriatic sturgeon (*Acipenser naccarii*) in Italy and the Atlantic European sturgeon (*Acipenser sturio*) in France. The population of these species decreased dramatically in common with most Eurasian sturgeon species due to damming, overfishing, pollution and poaching (Birstein, 1993). In France, to avoid additional detrimental effects on the population of the native sturgeon, experience was acquired on another sturgeon species, the Siberian sturgeon (*Acipenser baerii*) as a biological model. This species proved to be attractive for farming in mid 1980s in France. The status of sturgeon farming in Western Europe has been described recently (Rosenthal and Gessner, 1991; Williot et al., 1993; Bronzi et al., 1999). Nevertheless, some recent changes make it worthwhile to outline the progress made. Therefore, published information related to sturgeon farming are thus updated, new aspects are discussed, the most likely course of development of commercial sturgeon farming is pointed out, and perspectives of investigations are presented.

2. STURGEON FARMING

2.1. Species

In 1999, the dominant species (from a tonnage point of view) reared for production in western Europe were: the white sturgeon (*Acipenser transmontanus*) in Italy (46 %), the Siberian sturgeon (*Acipenser baeri*) in either France, Germany, Italy or Spain (35 %), the Adriatic sturgeon (*Acipenser naccarii*) in Italy and Spain (13 %) and the Russian sturgeon (*Acipenser gueldenstaedti*) at a low level in various countries (table I). In fact, in Italy the hybrid *A. naccarii* × *A. baeri* is produced for ongrowing and the pure species *A. naccarii* for restocking. In Germany, the bester hybrid between the beluga (*Huso huso*) and the sterlet (*Acipenser ruthenus*) is only of historical importance (Williot et al., 1993; Bronzi et al., 1999). The present sturgeon farming described is performed to provide meat and caviar for human consumption, plus recreational purposes, such as for aquarium fish and garden ponds as well as for the recreational fishing market. Up

to now Russian sturgeon and Siberian sturgeons as well as some hybrids have been the main subjects of these latter markets. It is noteworthy that various hybrids are still produced on a limited scale, including crosses between Siberian sturgeon, Russian sturgeon, green sturgeon (*Acipenser medirostris*), Adriatic sturgeon, sterlet, white sturgeon and beluga. Other pure species such as the stellate sturgeon (*Acipenser stellatus*), the beluga (Germany and Italy), and the paddlefish (*Polyodon spathula*) have been reared on a limited scale. The North American Atlantic sturgeon (*Acipenser oxyrinchus*) is being reared on an experimental level in some countries (Germany and Austria).

Currently, only two species native to some countries of Western Europe are being cultured for production purposes. One is the Adriatic sturgeon which has a confirmed range from the Italian to the previous Yugoslavian, as well as the Albanian waters, in the Adriatic Sea and a potential distribution around the Iberian peninsula (Garrido-Ramos et al., 1997; Hernandez et al., 1999). The second species is the Russian sturgeon, which was present in the Danube up to the Hungarian stretch (Vlasenko et al., 1989a; Pinter, 1991).

The sterlet, also endemic to the Danube, is reared on a very limited scale most probably due to its slow growth (1 vs. 6.5 kg for 5–7-year-old sterlet and Siberian sturgeon, respectively). The previously widespread pan-European species, *Acipenser sturio*, is currently considered as highly endangered and is the subject of restoration programmes (Williot et al., 1997; Kirschbaum et al., 2000).

2.2. Production systems

Sturgeon is farmed in different types of freshwater systems, utilising surface water, well water (including geothermal), and industrial wastewaters (including thermal effluents). It is noteworthy that even semi-anadromous species (Adriatic sturgeon and white sturgeon) are reared throughout their cycle in freshwater. The hatchery stage including broodfish management is relatively well known and described for a few species: Siberian sturgeon (Williot and Bourguignon, 1991; Williot, 1997; Williot and Brun, 1998; Williot et al., 2000), white sturgeon (Conte et al., 1988; Doroshov et al., 1997), and sterlet (Williot et al., in press). Water temperature, choice of best reproductive-potential spawners, hormonal treatment, collection of gametes etc. are known. With probably only minor adaptations, most of the other species could be similarly managed. Nevertheless this stage is of particular importance because sturgeon are late puberty fish even in rearing conditions, 5–6 and 6–8 years for male and female Siberian sturgeon respectively, 3–4 and 6–14 years for male and female white sturgeon (Doroshov et al., 1997). These ages are far earlier than in the wild. Moreover, oogenesis occurs mostly at a 2-year interval for the two species mentioned above. Weaning of larvae on compound diets is current on Siberian sturgeon, Russian sturgeon, sterlet and white sturgeon.

Table I. Production assessment for 1999 of sturgeon and caviar depending on countries and species in Western Europe. Total number of farms and production are given in bold.

Country/Species	Plants (No.) Hatchery/Ongrowing	Yearly production of meat (10 ³ t)	Yearly production of caviar (kg)
Austria	2/2	10	
A.b.	2/2	5	
A.g.	1/0	2	
A.r.	2/2	3	
Belgium	1/1	15	
A.b.	1/1	15	
France ^(a)	2/6	200	4 000
A.b.	2/6	200	4 000
Germany ^(b)	3/5	80	
A.b.	3/4	30	Near future
A.g.	0/1	15	
A.r.	1/1	5	
H.h.	1/2	10	
hyb.	2/4	20	
Greece ^(a)	0/1		
Hungary ^(a)	2/2		
A.g.	2/2	50 (potential)	Near future
Italy	4/10	800	2 000
A.t.	1/1	550	2 000
A.b. & hyb.	2/5	140	
A.n. & hyb.	1/4	110	
Poland	1/5	50	
A.b. & hyb.	1/5	50	
A.g.	0/2	10	
Spain	1/1	130	Near future
A.n.	1/1	120	
A.b.	1/1	10	
The Netherlands ^(b)	0/1	3	
A.g.	0/1	3	
A.s.	0/1		
A.b.	0/1		
Total	16/34	1 288 ^(b)	6 000

A.b.: *Acipenser baeri*; A.g.: *Acipenser gueldenstaedti*; A.n.: *Acipenser naccarii*; A.r.: *Acipenser ruthenus*; A.s.: *Acipenser stellatus*; A.t.: *Acipenser transmontanus*; H.h.: *Huso huso*; hyb.: hybrids.

^(a) One farm supplying the pet fish market; ^(b) potential production not included.

Other species need more care and sometimes live food is necessary.

Ongrowing of sturgeon is performed either in raceways or tanks with flowing water, in re-circulating systems or in ponds. The latter are of increased interest for females destined for caviar. Ponds are supplied with low water exchange rates and require relatively low investments especially earthen ponds. Stocking density is lower than in former systems, 1 to 5 kg·m⁻² as compared with a possible 30 to 40 kg·m⁻² respectively. Due to the behaviour of the fish (bottom feeder), earthen ponds may need some maintenance. In most cases, sturgeon is fed on commercial compound diets formulated for trout rearing. With the exception of two viruses that may lead to some damage on young white sturgeon (Hedrick et al., 1991) at present, pathology is not responsible for heavy losses. Treatments are known for most current diseases, especially myxobacteria on larvae. Marketable sizes are maximum 7–8 kg per fish for white sturgeon (Bronzi et al., 1999) and usually 1–4 kg for Siberian sturgeon. It should be

mentioned that a low percentage of fish exhibit morphological abnormalities which lead to death as result of their being incapable of eating due to a lack of equilibrium. A nutritive origin is suspected.

2.3. Production

An assessment of the 1999 production is given in table I. The total production of approximately 1 300 t is notably higher than the 900 t in preceding years (Bronzi et al., 1999). Meanwhile, a significant caviar production has developed in France and Italy that has reached 6 t, originating from two different species, Siberian and white sturgeon, respectively.

There are ongrowing farms, about half of them (16) also have a hatchery activity. In the same way as for other species, hatchery management requires specific prerequisites in term of funds, expertise and water supply.

Moreover, the fingerling production for both ongrowing and caviar production is much lower than that

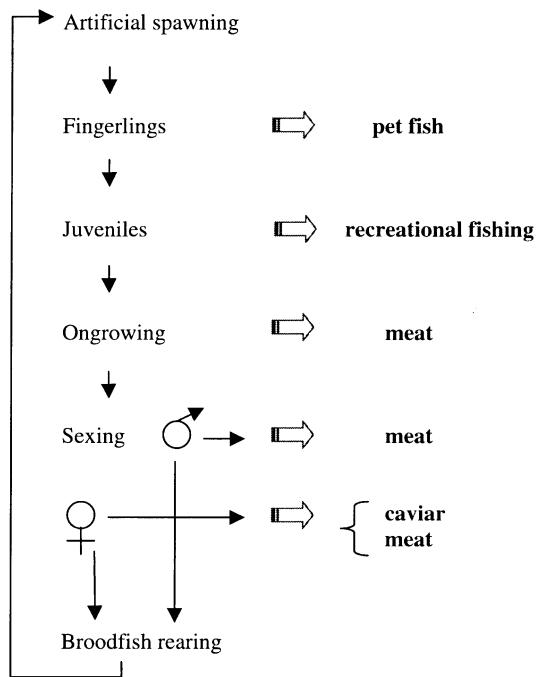


Figure 1. Main production steps and marketing products from sturgeon in Western Europe.

for the pet fish market. This indicates a present limitation of market capacity for sturgeon meat. This is due to the level of the production which is too low, and/or the fact that this is an unknown product. In addition, a market for juveniles to be stocked in ponds and exploited by recreational fishing also exists.

As a result, the overall production schedule given in *figure 1* summarizes the steps towards the various types of marketable products. The term 'meat' includes all types of end products, fresh or processed, packaged or not, that are not caviar. Usually, males are sold earlier, as soon as sex is determined. Together with the aquarium market, the sale of this male product yields an early income.

As far as caviar is concerned, there are thirteen different steps from female selection to preservation. These are: female selection, stunning, gutting, removal of ovaries, cooling, screening, rinsing, weighing, salting, draining, canning, labelling and preservation. Each step is of importance, the first (female selection) being the key one. It includes assessment of size, colour, firmness and the taste of ovarian follicles. This scheme is related to the production of a traditional caviar called 'malossol', prepared with 3–5 % salt and not pasteurised (Jubenot, 1992). This is potentially high quality caviar, which can be stored for 3 months at -2 or -3 °C or for 2 months at a temperature of $+2$ to $+4$ °C if a preservative (borax) is added (Williot and Sabeau, 1999). Current caviar yields are 10–15 % of total body weight.

2.4. Management

Many sturgeon production facilities have experienced a change of management and/or ownership (three out six in France). This indicates either that investment followed a misdirected marketing strategy or that the financial background of the enterprise was inadequate. High investments, overestimation of market volumes and sale prices, as well as an absence of marketing strategy were the difficulties experienced most often during the first phase of the industry's development. Moreover, caviar oriented production requires additional funds for extension of facilities and for enlarging stocks. For example, the standing crop for 7-year-old females destined for caviar production is three times that for a production of fish with 4 kg mean weight (4-year-old fish) in Siberian sturgeon.

These developments in management can be considered as a sign of a maturing activity. A surprising aspect is the total absence of former caviar traders in sturgeon farming up to now. This may either indicate the still-elevated risk in this business, its low profitability, the lack of anticipation of the sturgeon collapse in the Caspian Sea (see next section), or the lack of confidence in sturgeon rearing, especially for caviar.

3. CAVIAR MARKET SITUATION

Formerly, there were two main producers of sturgeon meat and caviar, the former USSR and Iran. Both utilised the Caspian Sea sturgeon stocks with the exception of Persian sturgeon (*Acipenser persicus*), inhabiting mostly the southern part of the Caspian Sea (Bourguignon, 1989; Vlasenko et al., 1989b; Williot and Bourguignon, 1991; Sternin and Doré, 1993). Today, five political entities are involved in the fishery, one of them is the Russian Federation represented by three republics: Russia, Kalmoukia and Dagestan. During the sixties, the mean annual caviar production of this region averaged 1 700 t, which increased in the 1970s to about 2 700 t, and then declined since the beginning of the 1980s (De Meulenaer and Raymakers, 1996). From this annual production, only 300–500 t were exported, representing the international caviar trade (Bourguignon, 1989; Williot and Bourguignon, 1991; De Meulanaer and Raymakers, 1996) of which the European Union consumed about 100 t (Bourguignon, 1989).

The decreasing trends in sturgeon landings and in caviar production were predicted 10 years ago (Williot and Bourguignon, 1991) and has now become a dramatic reality. Russian production is very low today (Ivanov et al., 1999; Luk'yanenko et al., 1999). The production in Iran has not only decreased (FAO, 1999), it has also shown signs of over-exploitation of stellate sturgeon (Moghim and Neilson, 1999). There are two main reasons for the collapse of the sturgeon fishery in the former USSR. One is water pollution, illustrated by the appearance of many abnormalities in sexual glands (Shagaeva et al., 1993; Akimova and

Ruban, 1996) and by high pesticide contents in roe (Kirschbaum et al., 1999). The other is the consequence of the adverse economic impact due to the breakdown of the former USSR, leading to intensive poaching. As a result, traditional caviar suppliers of the world market have disappeared or have become unimportant, at least those from the former USSR. Besides this consequence, the market has been supplied with a variety of products including low quality caviar originating from poaching, and reprocessed material from pasteurised stock. The lack of supply from natural catches and the continuous demand for caviar has increased prices for a number of years, thus opening the opportunity for aquaculture-produced caviar. Farming allows a more effective control over the end product and it ensures consumer satisfaction by guaranteeing quality standards. This gives a considerable advantage to the farmer.

4. PERSPECTIVES

It is noteworthy that sturgeon farming is a very special field of endeavour. Most of the farmed species in Western Europe are either endangered as far as their wild population are concerned (Adriatic sturgeon and Siberian sturgeon) and/or they are non-native (especially white sturgeon and Siberian sturgeon). In addition to the already mentioned disadvantages (late puberty, non-yearly oogenesis), the meat yield is rather low, at 40–50%. Nevertheless, in spite of these potentially negative aspects, sturgeon farming has a promising future.

4.1. Overall trends

Sturgeon fish are among the most promising temperate freshwater species for aquaculture in Western Europe. This kind of farming is also growing in California, based on white sturgeon (Struffenegger, 1992). They are temperature and oxygen tolerant, and they do not require specific rearing structures. In addition, the caviar market has an increasing demand that remains unfulfilled. There are some possibilities for diversification. One is product-related. This may depend on production: fingerlings, stocking material, meat or caviar. With regard to meat, different sizes may be proposed: whole, steak or fillet and various preparation procedures, fresh, processed or transformed. As far as caviar is concerned, the traditionally processed caviar, malossol, will compete with some variants in processing (flash pasteurised, pasteurisation) to increase the conservation duration. It is also probable that attempts to elaborate 'caviar-like' products from ovulated eggs will appear because the female might be used several times in this way. Up to the present, such experiments have failed. The last way for diversification could be species-related, in promoting some differences in texture and flavour comparable to the development witnessed in the foie gras and salmon markets.

4.2. Production composition

Most probably, the proportion of hybrids in production will decrease further because of the high cost of establishing two different broodstocks and the uncertainty in the advantage (with the exception of the specific situation as in Italy with the Adriatic sturgeon). Indeed, the relative importance of better in Germany has already decreased. The only benefit in using hybrids could lie in their sterility (in the case of interploid fish diploid \times tetraploid) so as to avoid interference with wild stocks in the case of accidental or intentional release.

Apart from these considerations, the relative importance of species is not expected to change rapidly, owing to long biological cycles, especially when caviar production is the objective. However, the relative importance of Siberian sturgeon as well as Russian sturgeon will increase because they are either the most widespread species or already subject to several on-growing projects.

4.3. Marketing and legal prerequisites

The future competition for markets will take place mainly within European countries, but also at world level with already existing producers in the USA and new ventures arising in countries like China and Chile. At least within the European Union, the rules of competition should be harmonised, including those guidelines concerning species as well as the strict definition and appellation of caviar, processes and related products. To this end, a strong professional organisation would be very helpful.

4.4. Research demands

Either public institutes (France) or private companies (Italy, Germany and Spain) initiated the first attempts at sturgeon production. Public research is now engaged, in Germany, in a restoration programme for Atlantic European sturgeon, and Italy has supported for some years the restocking in Adriatic sturgeon. As a result, there is little directly oriented European public research for farming. Nevertheless, there are evident common interests in some fields of investigation between species conservation and farming.

Five areas for further investigations linked to farming concerns may be distinguished: reserves of biological materials ('bank'), genetics, reproduction, farming and products. The first should allow for renewal of animals when needed as well as for later diversification, this means preservation of species, population, individuals and cells (gametes particularly spermatozoa), i.e. protection and conservation at all levels of the biological organisation. As a consequence of non-native and/or endangered status of farmed species, genetics investigations are of the utmost importance. They are necessary to characterise the variability of the farmed population and consequently

to organise the mating. This would also provide the tools to prove the origin of the fish (farmed stocks of now threatened or endangered species, CITES). Early sex identification through DNA investigation (Griffiths et al., 2000) should be helpful to better organise the rearing of unisex lines. Protocols for obtaining unisex lines depend on the genetic determination of sex. This should be explored all the more since, with the exception of white sturgeon species in which the females are WZ (Van Eenennaam et al., 1999), sex determination is unknown for other sturgeon species. And this genetics field is closely connected with reproduction, in particular for all female lines destined for caviar production.

To prevent any cross breeding with native species when escapes occur, production of sterile fish for either human consumption or recreational purposes should be promoted. One strategy was mentioned above, the interploidy crossing, in the sturgeon situation: $(2n = 116-120) \times (2n = 239-250)$. Another possibility could be the artificial increase of ploidy as usually a triploid individual is sterile. In captivity, sturgeon need to be hormonally stimulated to provide gametes. Different hormones may be used, carp pituitary homogenate or some analogue of GnRH. The main problem is to choose the spawners that have the best predictable reproduction potential. Great improvements were achieved through the *in vitro* maturation competence of ovarian follicles (Lutes et al., 1987; Williot and Bourguignon, 1991; Goncharov, 1993). Nevertheless, prediction remains imprecise because gonadotrope hormones, which are not available, are substituted with progestagens. These hormones are used to mimic *in vitro* the maturation of ovarian follicles. Then the functionality of surrounding cells, normally involved in the endocrinological pathway, is shunted and it is known that in some circumstances (stress and unfavourable thermal history) they may lose their functionality (Dettlaff and Davydova, 1979). It may be suggested that the activity of different enzymes of the surrounding cells involved in the final production of the maturation inducing steroids be investigated. Concurrently, *in vitro* ovulation should be explored. There is no criterion available for males that can be used to predict the quality of semen.

The fourth field for potential investigation concerns farming. Larval rearing requires some attention because it might be considered as the end step of reproduction, the final test of the quality of the gametes. Moreover, some sturgeon species are difficult to wean on compound diets as already stated above. The reasons for this are unknown. An exploration of the microflora of the digestive tract, which plays an important role in assimilation of nutrients, may be profitable. More generally, food and feeding together with stocking density and water temperature should be investigated in relation to the quality of end products, meat and caviar. At present, farmers use trout compound diets. As long as sturgeon production remains at a relatively low level, food providers will not elaborate

specific sturgeon food. Nevertheless, some investigations were carried out, particularly on Siberian sturgeon (Kaushik et al., 1989, Kaushik et al., 1991; Médale and Kaushik, 1991).

The last field of potential investigation is related to the end products themselves. How should the fish be prepared before any processing? Flavour should be determined in a standard way. The use of recent 'artificial nose' developments might be tried in order both to establish correlation with rearing conditions and/or to lead to what is asked for by the markets. Public research is engaged mainly in conservation, i.e. the biological reserve mainly for the Atlantic European sturgeon. As a result, some investigations are carried out in genetics, reproduction and feeding, the last two being performed on Siberian sturgeon as a biological model. In this light, some biological tools or results are of use for farming. With regard to the length of biological cycles, those farmers with a good knowledge of both the genetic pool and economical functioning of their farms (including meat and caviar alternatives) will be in a good position to face future competition.

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